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TECHNICAL MEMORANDUM 2103

(C) TRANSVERSE MOTION OF 8 INCH PROJECTILE, XM673, IN THE XM201, M2A2 GUN TUBE, MK-16 AND MCLG GUN (U)

BY

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ABSTRACT

The dynamic behavior of a projectile during acceleration in the gun tube requires a quantitative discription, since if balloting becomes excessive, undesirable conditions such as damage to fuzing. shell body engraving, inaccuracy of fire due to yaw, and yaw velocity at the muzzle may result. The approach taken in this report utilize the equations of motion derived in an earlier report titled, "Transverse Motion of an Accelerating Shell" [1] to describe the balloting motion of the 8-inch XM673 projectile fired in the MK-16, MCLG gun, XM201 and M2A2 gun tubes.

Most previous solutions which have appeared in published works to date discuss the problem in a simple way, or consider separately the main factors that effect projectile motion. Effects of friction forces at the bourrelet and the driving band, changes of the eccentricity and the location of the center of gravity, and the wall thickness of the shell were considered in this formulation.

The analysis shows that the contact of the bourrelet on the gun tube is intermittent when the C. G. eccentricity is zero or very small and the contact is continuous when the eccentricity is large and that this parameter is the one that most effects the performance of the projectile and the associated fuze. The analytical results are presented in graphic form.

INTRODUCTION

As part of the design and evaluation of the 8 inch XM673 projectile, an analysis was performed of the balloting motion of the projectile if fired from each of the MK-16 and MCLG guns and the M2A2 and XM201 gun tubes. Since the projectiles are precisely machined it is assumed that the projectile configuration is symmetrical about its geometrical axis, which is taken as the 3'-axis of the moving body coordinate system 1', 2', 3' (Fig. 1). The mass distribution of the projectile was considered to have various degrees of non-uniformity. For zero eccentricity, the center of gravity of the projectile will be at the 3'-axis, otherwise it has an eccentricity of some magnitude from the 3'-axis. As in Reference 1, another moving body coordinate system 1, 2, 3 was selected and made parallel to the 1', 2', 3' system with its origin at the center of gravity of the projectile. Since the eccentricity of the center of gravity is usually small, it is assumed that the products of inertia of the projectile about the coordinate system 1, 2, 3 may be ignored and that the projectile has constant polar and transverse moments of inertia about this moving coordinate system.

The calculation is done with the assumption that the gun tube is rigid, stationary, and straight, and the geometrical projectile axis always intersects the center of the driving band diameter and that the latter is always centered along the gun tube axis. The 3-axis of the coordinate system 1, 2, 3 may or may not coincide with the 3'-axis of the system 1', 2', 3', but the corresponding axes are parallel to each other. The eccentricity, ϵ, is expressed in inches and is the distance between the 3- and the 3'-axis. It may also be expressed in terms of the moment (in-oz) of the projectile weight about the geometrical axis of the projectile, i.e. the product of the projectile weight (oz.) and the eccentricity distance (in.). Hence the eccentricity distance (in.) is equal to the eccentricity moment (in-oz.) divided by the projectile weight (oz.) Four cases with ϵ = 0, 10, 25 and 50 in-oz respectively and a projectile wall thickness t = 0.40 in. are computed for each type of gun tube to show the effects of the eccentricity. To investigate the effects of (1) friction forces, (2) projectile wall thickness and (3) location of center of gravity

of the projectile, cases with (1) no friction forces, (2) wall thicknesses of 0.38 and 0.42 inches respectively, and (3) distance from the bourrelet to the driving band unchanged but with the distance from the center of gravity to the driving band reduced to three quarters and one half the original value respectively, are computed for the XM201 gun tube only.

In these computations the equations of motion derived in Reference 1 have been used with the additic : of friction forces, both at the bourrelet and the driving band, to increase the accuracy of the computation.

THEORY

The coordinate systems and Euler's angles used in the computations are shown in Fig. 1. The Z-axis is taken along the gun tube and gun elevation is 45 degrees with the X-axis positioned horizontally and the Y-axis perpendicular. Consequently, the angle α used in the following equations of motion is taken as 135 degrees.

The equations of motion are derived in the same way as shown in Reference 1 with the exception that the friction forces and their associate moments are added to the original forces and moments at the bourrelet and the driving band. For easy understanding of the computations and completness of this report, some of these equations and the related definitions of symbols are repeated below.

The six equations of motion are:

$$
\begin{aligned}
& m\ell[\ddot{\theta} \cos\theta \sin\psi + \ddot{\psi} \sin\theta \cos\psi - (\dot{\psi}^2 + \dot{\theta}^2) \sin\theta \sin\psi + 2\dot{\psi}\dot{\theta} \cos\theta \cos\psi] \\
& -m\epsilon[\ddot{\phi}(\sin\phi \cos\psi + \cos\phi \cos\theta \sin\psi) + \ddot{\psi}(\cos\phi \sin\psi + \sin\phi \cos\theta \cos\psi) \\
& -\dot{\theta}^2 \sin\phi \cos\theta \sin\psi - 2\dot{\phi}\dot{\psi}(\sin\phi \sin\psi - \cos\phi \cos\theta \cos\psi) \\
& -\ddot{\theta} \sin\phi \sin\theta \sin\psi + (\dot{\psi}^2 + \dot{\phi}^2)(\cos\phi \cos\psi - \sin\phi \cos\theta \sin\psi)
\end{aligned}
$$

$$-2\dot{\phi}\,\dot{\theta}\,\cos\phi\sin\theta\sin\psi - 2\dot{\psi}\,\dot{\theta}\,\sin\phi\sin\theta\cos\psi]$$

$$= (F_{b1} + F_{c1})\cos\psi - (F_{b2} + F_{c2})\cos\theta\sin\psi + (F_{b3} + F_{c3}$$

$$+ Ap\sec\theta)\sin\theta\sin\psi \qquad (1)$$

$$m\ell[\ddot{\psi}\sin\theta\sin\psi - \ddot{\theta}\cos\theta\cos\psi + (\dot{\psi}^2 + \dot{\theta}^2)\sin\theta\cos\psi + 2\dot{\psi}\dot{\theta}\cos\theta\sin\psi]$$

$$+ m\epsilon[\ddot{\phi}(\cos\phi\cos\theta\cos\psi - \sin\phi\sin\psi) + \ddot{\psi}(\cos\phi\cos\psi - \sin\phi\cos\theta\sin\psi)$$

$$-\ddot{\theta}\sin\phi\sin\theta\cos\psi - (\dot{\psi}^2 + \dot{\phi}^2)(\cos\phi\sin\psi + \sin\phi\cos\theta\cos\psi)$$

$$-\dot{\theta}^2\sin\phi\cos\theta\cos\psi - 2\dot{\phi}\dot{\theta}\cos\phi\sin\theta\cos\psi + 2\dot{\psi}\dot{\theta}\sin\phi\sin\theta\sin\psi$$

$$-2\dot{\phi}\dot{\psi}(\cos\phi\cos\theta\sin\psi + \sin\phi\cos\psi)]$$

$$= (F_{b1} + F_{c1})\sin\psi + (F_{b2} + F_{c2})\cos\theta\cos\psi - (F_{b3} + F_{c3} + Ap\sec\theta)\sin\theta\cos\psi$$

$$+ mg\cos\alpha \qquad (2)$$

$$m\ddot{W} - m\ell(\ddot{\theta}\sin\theta + \dot{\theta}^2\cos\theta) + m\epsilon[\ddot{\phi}\cos\phi\sin\theta + \ddot{\theta}\sin\phi\cos\theta$$

$$-(\dot{\phi}^2 + \dot{\theta}^2)\sin\phi\sin\theta + 2\dot{\phi}\dot{\theta}\cos\phi\cos\theta]$$

$$= (F_{b2} + F_{c2})\sin\theta + (F_{b3} + F_{c3} + Ap\sec\theta)\cos\theta - mg\sin\alpha \qquad (3)$$

$$I(\ddot{\theta} - \dot{\psi}^2\sin\theta\cos\theta) + I_3\dot{\psi}(\dot{\psi}\cos\theta + \dot{\phi})\sin\theta$$

$$= M_{b1} + M_{c1} - Ap\epsilon\sin\phi\sec\theta \qquad (4)$$

$$I(\ddot{\psi}\sin\theta + 2\dot{\psi}\dot{\theta}\cos\theta) - I_3\dot{\theta}(\dot{\psi}\cos\theta + \dot{\phi})$$

$$= M_{b2} + M_{c2} + Ap\epsilon\cos\phi\sec\theta \qquad (5)$$

$$I_3(\ddot{\psi}\cos\theta+\ddot{\phi}-\dot{\psi}\dot{\theta}\sin\theta)$$

$$= M_{b3}+M_{c3} \tag{6}$$

where ψ, θ, ϕ = Euler's angles (radians), $\dot{\psi}, \dot{\theta}, \dot{\phi}$ and $\ddot{\psi}, \ddot{\theta}, \ddot{\phi}$ are the corresponding velocities (rad/sec) and accelerations (rad/sec^2) respectively

ℓ = distance from C.G. to driving band (in)

ϵ = eccentricity of C.G. from geometrical projectile axis (in.)

A = area of bore (in.^{2})

α = Y-axis inclination to the horizontal line (radians)

W = axial displacement of driving band diameter center (in.). $\dot{W}$ and $\ddot{W}$ are the corresponding velocity (in/sec) and acceleration (in/sec^2).

g = gravitational acceleration, 386 in/sec^2

m = mass of projectile (lb $-$in^{-1} $-$sec^2)

I = transverse mass moment of inertia of projectile (lb -in -sec^2)

I_3 = polar mass moment of inertia of projectile (lb -in -sec^2)

p = firing pressure (psi)

F_{b1}, F_{b2}, F_{b3} = total bourrelet contact force components along the 1-, 2-, and 3-axis respectively (lbs.)

F_{c1}, F_{c2}, F_{c3} = total driving band contact force components along 1-, 2-, and 3-axis respectively (lbs.)

M_{b1}, M_{b2}, M_{b3} = total moment components of bourrelet contact forces about the 1-, 2-, and 3-axis respectively (in-lb)

M_{c1}, M_{c2}, M_{c3} = total moment components of driving band forces about the 1-, 2-, and 3-axis respectively (in-lb)

The friction forces are equivalent to the products of the normal forces and the frictional coefficients. The friction coefficient for the bourrelet contact is taken as that of dry sliding of mild steel on mild steel, equal to 0.57 [2]. The friction coefficient at the driving band contact is obtained from several trial computations. First a frictional coefficient is assumed for use in calculating the travle and velocity of the projectile. The results are then compared to those from interior ballistics computations with the same firing pressure. The computation is repeated, varying the friction coefficient until a reasonable agreement is reached, and then that coefficient is taken as the desired one. The normal forces are obtained from the contact forces at the bourrelet and the driving band. The compressive pressure exerted on the driving band by the gun tube is also included. Since there are no simple equations available for this pressure calculation, an approximate pressure distribution of 40,000 and 20,000 psi based on average experimental maximum and mimimum data is assumed at the breech and the muzzle portion, respectively, in the computation.

With the addition of the friction forces and their associated moments at the bourrelet and the driving band contact, the total components of the forces and moments may be computed with the following equations:

The total forces and moments at the bourrelet contact are:

$$F_{b1} = \frac{-\mu_b E t^3 R\theta(\dot{\psi}+\dot{\phi}\cos\theta)\left[r\cos\theta + \frac{\theta}{|\theta|}(h+\ell)\sin\theta - R\right]}{0.135 r^2 |\theta| \sqrt{\left(\dot{W} - \frac{R\theta\dot{\theta}}{|\theta|}\right)^2 + R^2(\dot{\psi}+\dot{\phi}\cos\theta)^2}} \qquad (7)$$

$$F_{b2} = \frac{Et^3}{0.135r^2}\left[r\cos\theta + \frac{\theta}{|\theta|}(h+\ell)\sin\theta - R\right]$$

$$\times\left[\frac{\theta}{|\theta|}\cos\theta - \frac{\mu_b\left(\dot{W} - \frac{R\theta\dot{\theta}}{|\theta|}\right)\sin\theta}{\sqrt{\left(\dot{W} - \frac{R\theta\dot{\theta}}{|\theta|}\right)^2 + R^2(\dot{\psi}+\dot{\phi}\cos\theta)^2}}\right] \tag{8}$$

$$F_{b3} = -\frac{Et^3}{0.135r^2}\left[r\cos\theta + \frac{\theta}{|\theta|}(h+\ell)\sin\theta - R\right]$$

$$\times\left[\frac{\theta}{|\theta|}\sin\theta + \frac{\mu_b\left(\dot{W} - \frac{R\theta\dot{\theta}}{|\theta|}\right)\cos\theta}{\sqrt{\left(\dot{W} - \frac{R\theta\dot{\theta}}{|\theta|}\right)^2 + R^2(\dot{\psi}+\dot{\phi}\cos\theta)^2}}\right] \tag{9}$$

$$M_{b1} = -\frac{Et^3}{0.135r^2}\left[r\cos\theta + \frac{\theta}{|\theta|}(h+\ell)\sin\theta - R\right]$$

$$\times\left\{\frac{h\theta\cos\theta}{|\theta|} - \left(r + \frac{\epsilon\theta}{|\theta|}\sin\phi\right)\sin\theta - \frac{\mu_b\left[h\sin\theta + \frac{\theta}{|\theta|}\left(r + \frac{\epsilon\theta}{|\theta|}\sin\phi\right)\cos\theta\right]\left(\dot{W} - \frac{R\theta\dot{\theta}}{|\theta|}\right)}{\sqrt{\left(\dot{W} - \frac{R\theta\dot{\theta}}{|\theta|}\right)^2 + R^2(\dot{\psi}+\dot{\phi}\cos\theta)^2}}\right\} \tag{10}$$

$$M_{b2} = -\frac{Et^3}{0.135r^2}\left[r\cos\theta + \frac{\theta}{|\theta|}(h+\ell)\sin\theta - R\right]$$

$$\times\left\{\frac{\theta\sin\theta}{|\theta|} + \frac{\mu_b\left[\frac{h\theta R}{|\theta|}(\dot{\psi}+\dot{\phi}\cos\theta) + \left(\dot{W} - \frac{R\theta\dot{\theta}}{|\theta|}\right)\cos\theta\right]}{\sqrt{\left(\dot{W} - \frac{R\theta\dot{\theta}}{|\theta|}\right)^2 + R^2(\dot{\psi}+\dot{\phi}\cos\theta)^2}}\right\} \tag{11}$$

$$M_{b3} = -\frac{Et^3}{0.135r^2}\left[r\cos\theta + \frac{\theta}{|\theta|}(h+\ell)\sin\theta - R\right]$$

$$\times\left\{\frac{\mu_b\left[R(\dot\psi+\dot\phi\cos\theta)\left(r+\frac{\epsilon\theta}{|\theta|}\sin\phi\right) + \epsilon\left(\dot W - \frac{R\theta\dot\theta}{|\theta|}\right)\sin\theta\cos\phi\right]}{\sqrt{\left(\dot W - \frac{R\theta\dot\theta}{|\theta|}\right)^2 + R^2(\dot\psi+\dot\phi\cos\theta)^2}} \qquad (12)$$

$$\left. - \frac{\epsilon\theta}{|\theta|}\cos\theta\cos\phi\right\}$$

and the components of the total forces and moments at the driving band are:

$$F_{c1} = \frac{\pi}{2} f_{sm} R(\sin\psi_s + \mu_c \sin\gamma\cos\psi_s) \qquad (13)$$

$$F_{c2} = \frac{-\pi R f_{sm}}{2}\left(\cos\psi_s \cos\theta + \frac{4}{\pi}\mu_c\cos\gamma\sin\theta\right.$$

$$\left. - \mu_c \sin\gamma\sin\psi_s \cos\theta\right) - 2\pi R\left[f_n(\sin\gamma + \mu_c \cos\gamma)\right.$$

$$\left. + \mu_c p_c d \cos\gamma\right]\sin\theta \qquad (14)$$

$$F_{c3} = \frac{\pi R f_{sm}}{2}\left(\cos\psi_s \sin\theta - \frac{4}{\pi}\mu_c \cos\gamma\cos\theta\right.$$

$$\left. - \mu_c \sin\gamma\sin\psi_s \sin\theta\right) - 2\pi R\left[f_n(\sin\gamma + \mu_c \cos\gamma)\right.$$

$$\left. + \mu_c p_c d \cos\gamma\right]\cos\theta \qquad (15)$$

$$M_{c1} = -2\pi R f_n(\ell\sin\theta - \epsilon\cos\theta\sin\phi)(\sin\gamma + \mu_c \cos\gamma)$$

$$- \frac{R f_{sm}}{2}\left\{\pi\left[\ell\cos\theta - \left(\frac{8R}{3\pi}\cos\phi_s - \epsilon\sin\phi\right)\sin\theta\right]\right.$$

$$\times(\cos\psi_s - \mu_c \sin\gamma\sin\psi_s) + 4\mu_c\cos\gamma\left[\ell\sin\theta\right.$$

$$\left.\left. + \left(\frac{\pi R}{4}\cos\phi_s - \epsilon\sin\phi\right)\cos\theta\right]\right\}$$

$$- 2\pi \mu_c R p_c d \cos\gamma (\ell \sin\theta - \epsilon \cos\theta \sin\phi) \qquad (16)$$

$$M_{c2} = 2\pi R f_n [R(\cos\gamma - \mu_c \sin\gamma) \sin\theta$$

$$- \epsilon \cos\theta \cos\phi (\sin\gamma + \mu_c \cos\gamma)]$$

$$+ \frac{R f_{sm}}{2} \Big\{ \pi [(\frac{8R}{3\pi} \sin\phi + \epsilon \cos\phi)(\cos\psi_s - \mu_c \sin\gamma \sin\psi_s) \sin\theta$$

$$- \ell(\mu_c \sin\gamma \cos\psi_s + \sin\psi_s)] - 4\mu_c [(\frac{\pi R}{4} \sin\phi_s + \epsilon \cos\theta)$$

$$\times \cos\gamma \cos\theta + \frac{R}{3} \sin\gamma \sin\theta] \Big\} - 2\pi \mu_c R p_c d (\epsilon \cos\gamma \cos\theta \cos\phi$$

$$+ R \sin\gamma \sin\theta) \qquad (17)$$

$$M_{c3} = 2\pi R f_n [R (\cos\gamma - \mu_c \sin\gamma) \cos\theta$$

$$+ \epsilon (\sin\gamma + \mu_c \cos\gamma) \cos\phi \sin\theta]$$

$$+ 2\pi \mu_c R p_c d (\epsilon \cos\gamma \sin\theta \cos\phi - R \sin\gamma \cos\theta)$$

$$+ \frac{R f_{sm}}{2} \Big\{ \pi [(\frac{8R}{3\pi} \sin\phi_s + \epsilon \cos\phi)(\cos\psi_s - \mu_c \sin\gamma \sin\psi_s) \cos\theta$$

$$- (\frac{8R}{3\pi} \cos\phi_s - \epsilon \sin\phi) (\mu_c \sin\gamma \cos\psi_s + \sin\psi_s)]$$

$$+ 4\mu_c [(\frac{\pi R}{4} \sin\phi_s + \epsilon \cos\phi) \cos\gamma \sin\theta - \frac{R}{3} \sin\gamma \cos\theta] \Big\} \qquad (18)$$

where E = Young's modulus of projectile wall material, psi

r = radius of projectile, in.

t = thickness of projectile wall, in.

R = radius of bore, in.

d = width of driving band, in.

h = distance from C.G. to the bourrelet, in.

$|\theta|$ = absolute value of θ, rad. $\frac{\theta}{|\theta|}$ is used to change the sign of the related quantity when θ becomes negative

μ_b = friction coefficient at the bourrelet

μ_c = friction coefficient at the driving band

f_{sm} = maximum side normal force at the driving band per unit of circumferential length, lb/in

f_n = uniform force normal to the forward surface of the square rifling grooves per unit of circumferential length, lb/in

p_c = driving band pressure, psi

γ = twist angle of rifling, rad.

ϕ_s = angle from the diameter of the region where the side forces are acting at the driving band to the node axis or 1-axis, rad.

ψ_s = projection of ϕ_s angle on the cross-sectional plane of the gun tube, rad.

The displacement of the center of the driving band diameter is related to the other quantities by the equation

$$\dot{W} \tan \gamma = R\,(\dot{\psi} + \dot{\phi} \cos \theta) \tag{19}$$

INPUT DATA FOR COMPUTATIONS

Computations were performed for the 8 inch, XM673 projectile fired in the XM201 and M2A2 gun tubes, and MCLG and MK-16 guns respectively. The shell has the following dimensions and

properties:

L (distance from driving band to bourrelet) = 11.539 in.

ℓ (distance from driving band to C. G.) = 9.266 in. (6.950 and 4.633 in. respectively are used to compute the effect of change of C. G. location for the XM201 gun tube)

h (distance from bourrelet to C. G.) = L - ℓ

s (distance from C. G. to nose of projectile) = 26.87 in.

t (wall thickness) = .40 in. (.38 and .42 in. respectively are used to compute the effect of wall thickness for the XM201 gun tube)

ϵ (eccentricity of C. G. from the geometrical axis of projectile) = 0, 10, 25 and 50 in-oz (i.e. 0, .00313, .00781 and .01563 in. eccentricity distance)

E (Young's modulus for the projectile steel) = 30×10^6 psi

I (transverse weight moment of inertia) = 15745 lb-in^2

I_3 (polar weight moment of inertia) = 1831 lb-in^2

mg (weight of projectile) = 200 lbs.

r (radius of projectile bourrelet) = 3.997 in

All the guns have a bore of 8.00 inches and are positioned at the elevation of 45 degrees so that α value used in the computation is 135 degrees or 2.356 radians. The other characteristics of the guns are:

Gun or Gun Tube Type	TL(Travel), in.	γ(Twist Angle), deg.
XM201	274.0	8.92705
M2A2	168.0	7.16246
MK-16	388.7	7.16246
MCLG	394.4	8.92705

The initial conditions of the shell for all computations are taken as:

$\psi = 0,\quad \dot{\psi} = 0,\quad X = 0,\quad \dot{X} = 0,$

$\theta = .0001 \text{ rad.},\quad \dot{\theta} = 0,\quad Y = 0,\quad \dot{Y} = 0,$

$\phi = 0,\quad \dot{\phi} = 0,\quad Z = 0,\quad \dot{Z} = 0,$

The coefficient of friction μ_b at the bourrelet was taken as .57 and that at the driving band, μ_c, was determined by the method described earlier to be .004, .009, .02 and .02 for XM201, M2A2 gun tubes, MK-16 and MCLG guns, respectively.

The firing pressure for the various guns or gun tubes used in the computations are the given base pressures as shown in Figs. 2a, 2b, 24, 31 and 38, respectively. The same firing pressure is used for all computations for the respective gun or gun tube.

RESULTS OF COMPUTATIONS AND DISCUSSION

The results of computations are presented by the following figures:

Figs. 2a, 2b, 24, 31 and 38 show the base firing pressure and the travel of the shell inside the gun tube with respect to time (milliseconds) for the XM201, M2A2 gun tube, MCLG and MK-16 gun respectively. The base firing pressure was given and the travel was computed. The same given firing pressure is used for computations of all cases of the same type of gun tube

or gun. The travel variations of different cases of the same type of gun tube or gun are very small. Consequently, the pressure and the travel curves of various cases for each type of gun tube or gun are presented by one curve respectively.

Figs. 3a, 3b, 25, 32 and 39 show the computed velocity and the acceleration at the center of gravity of the projectile with respect to the time for the XM201, M2A2 gun tube, MCLG and MK-16 gun respectively. The variations in velocity and acceleration become noticeable only near the end of firing when the firing pressure is decreasing rapidly. But they are still of very small magnitude. Consequently, the corresponding travel variations are also very small as mentioned before.

Figs. 4-7, 26, 33 and 40 present the paths or the polar positions of the C. G. and the bourrelet center as seen from the muzzle down to the breech, for the various cases of the XM201, M2A2 tube, MCLG and MK-16 gun. The R value denotes the scale of the drawing and it is the radius of the circle in inches. It is seen that when there is no or small C. G. eccentricity the shell will make intermittent contact with the gun tube, but contact is continuous as the eccentricity increases. The friction forces will retard the rotation of the shell with respect to the gun tube. The polar distance of both the C. G. and the bourrelet center decrease with thicker walled shell and shorter distance between the C. G. and the driving band. The precession angle is retarded by friction and low values of eccentricity.

Figs. 8-11, 27, 34 and 41 show the results of computations of the angular positions (in degrees) of the contact points on the gun tube and the bourrelet of the projectile respectively with respect to the projectile travel (inches), for the XM201, M2A2 gun tube, MCLG and MK-16 gun. The deflection at the bourrelet, normal to the gun tube wall, is also plotted. It is again seen that the contact of bourrelet on the gun tube is intermittent when the C. G. eccentricity is zero or very small, and the contact is continuous when the eccentricity is large. The path of the contact point on the bourrelet is not always a horizontal straight line when plotted against projectile travel, which indicates that the motion of the projectile may not be considered as that of a compound pendulum with its oscillation plane rotating about the

gun tube axis. The frictional forces seem to cause the precession angle to be smaller than for the no friction cases, however, the presence of eccentricity is a more significant factor. The deflection at the bourrelet increases with larger magnitude of the eccentricity, thinner projectile wall and longer distance between the C. G. and the driving band, respectively.

Figs. 12-15, 28, 35, and 42 present the computed results of the angles, velocities and accelerations of yaw for different cases of the XM201, M2A2 gun tube, MCLG and MK-16 gun. The effect of increasing the C. G. eccentricity or the projectile wall thickness, and decreasing the friction or the C. G. to driving band distance, respectively seem to increase the variation frequency in the yaw angle, velocity and acceleration of the projectile.

Figs. 16-19, 29, 36, and 43 show the results of computations of accelerations normal to the projectile axis and at the C. G., the bourrelet center, and the axial points with a distance from the projectile nose equal to 2.5, 5.0, 7.5, and 15.0 inches, respectively, for the XM201, M2A2 gun tube, MCLG and MK-16 gun. They indicate that the normal accelerations will increase when the C. G. eccentricity is increased or when there is no friction. The variation frequency of the normal acceleration seems to increase with projectile wall thickness or shorter C. G. to driving band distances.

Figs. 20-23, 30, 37 and 44 show the forces acting on the projectile at the contact point of the bourrelet with the gun tube against the time (ms), for the XM201, M2A2 gun tube, MCLG and MK-16 gun, respectively. The force component F_1 is in the direction of the yaw or nutation axis, F_2 is perpendicular to both the yaw and the shell axis, and F_3 is along the shell axis. Their magnitudes are presented in terms of mg's or in weights of the shell. It is seen that the forces will increase with greater C. G. eccentricity, shell wall thickness and distance between the C. G. and the driving band. The force component F_1 is zero and F_3 nearly zero when there is no friction.

A summary of some results is presented in Table I.

CONCLUSION AND RECOMMENDATIONS

Based on the calculated data and as indicated in the discussion, it is concluded that the eccentricity of the center of gravity of the projectile from its geometrical axis has the greatest effect on the motion of the shell inside the gun tube. The motion of the shell becomes more complicated when the eccentricity is increased. The motion may not be considered as that of a compound pendulum with its oscillation plane rotating about the gun tube axis. When eccentricity is very high, this condition tends to be approached. The deflection at the bourrelet, the yaw angle, the normal acceleration of axial points and the bourrelet contact force are increased with larger C.G. eccentricity.

Since the increase of the C.G. eccentricity increases rapidly the bourrelet contact force and the normal accelerations at the axial points of the shell and these quantities may affect the performance of the shell and the associated fuze, it is therefore recommended that the C.G. eccentricity be made as small as possible so as to improve the shell performance.

REFERENCES

1. Chu, S. H. and Soechting, F. K.: Transverse Motion of an Accelerating Shell, Technical Report 4314, Picatinny Arsenal, Dover, NJ, June 1972.

2. Baumeister, Theodore and Marks, Lionel S. (Editors): Standard Handbook for Mechanical Engineers, Seventh Edition, page 3-35, McGraw-Hill Book Company, 1967.

TABLE I SUMMARY OF RESULTS

GUN OR GUN TUBE TYPE	SHELL WALL THICKNESS, in.	C.G. ECCENTRICITY, in-oz.	VELOCITY AT MUZZLE fps	PEAK AXIAL ACC., g's	YAW AT MUZZLE Angle, 10^{-6} rad.	YAW AT MUZZLE Velocity 10^{-3} rad/sec (Abs. Value)	PEAK NORMAL ACC. AT FUZE (2.5 in. FROM SHELL NOSE) g's	PEAK LATERAL FORCE AT BOURRELET, mg's
XM201	.40	0	2507	8500	63	33	14	10
	.40	10	2504	8500	1197	153	103	48
	.40	25	2496	8496	2318	498	228	112
	.40	50	2486	8488	3853	471	393	196
XM201 No Friction	.40	0	2530	8548	170	66	15	8
	.40	10	2530	8548	1147	130	136	54
	.40	25	2530	8548	2386	566	264	110
	.40	50	2530	8548	4405	971	503	214
XM201	.38	25	2497	8494	2582	261	218	102
	.42	25	2496	8498	1684	405	222	114
XM201 Original C.G. to Driving Band Distance Reduced By: 3/4	.40	25	2499	8498	1679	1116	211	85
1/2	.40	25	2501	8498	1882	96	255	83

TABLE I SUMMARY OF RESULTS (Continued)

GUN OR GUN TUBE TYPE	SHELL WALL THICKNESS, in.	C.G. ECCENTRICITY in-oz.	VELOCITY AT MUZZLE fps	PEAK AXIAL ACC., g's	YAW AT MUZZLE		PEAK NORMAL ACC. AT FUZE (2.5 in. FROM SHELL NOSE) g's	PEAK LATERAL FORCE AT BOURRELET, mg's
					Angle, 10^{-6} rad.	Velocity 10^{-3} rad/sec (Abs. Value)		
M2A2	.40	0	1879	8300	264	73	12	9
	.40	10	1877	8300	761	58	46	26
	.40	25	1875	8296	899	181	61	38
	.40	50	1872	8290	1203	71	87	57
MCLG	.40	0	3050	8222	111	33	13	9
	.40	10	3045	8222	1052	120	103	46
	.40	25	3032	8218	2297	1292	293	132
	.40	50	3015	8206	4199	1189	565	254
MK-16	.40	0	2811	6810	343	66	11	8
	.40	10	2805	6802	1064	571	108	55
	.40	25	2798	6798	1762	7	191	101
	.40	50	2787	6792	3448	802	317	172

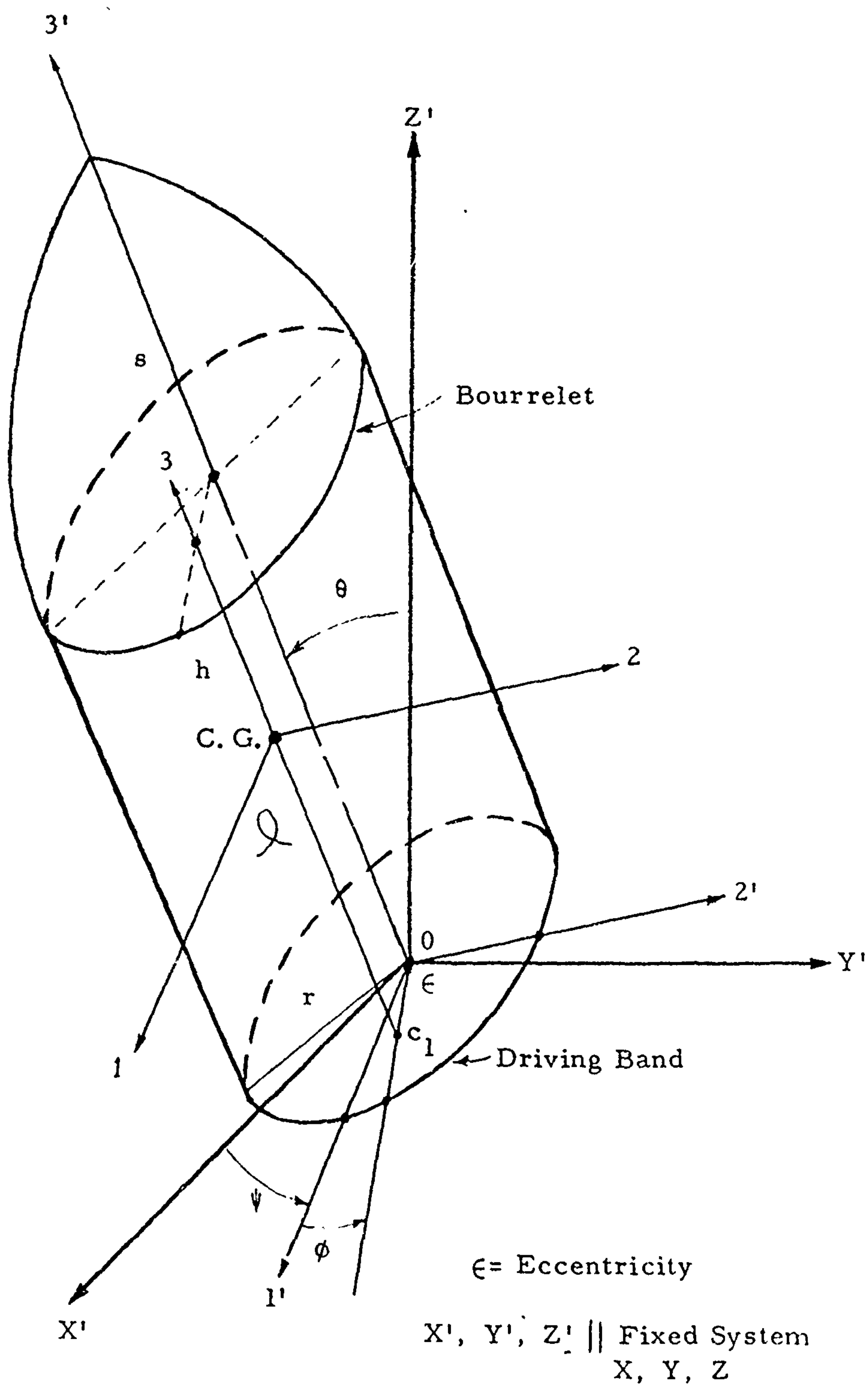


FIGURE 1

Coordinate Systems and Euler's Angles

XM201 TUBE

FIGURE 2a

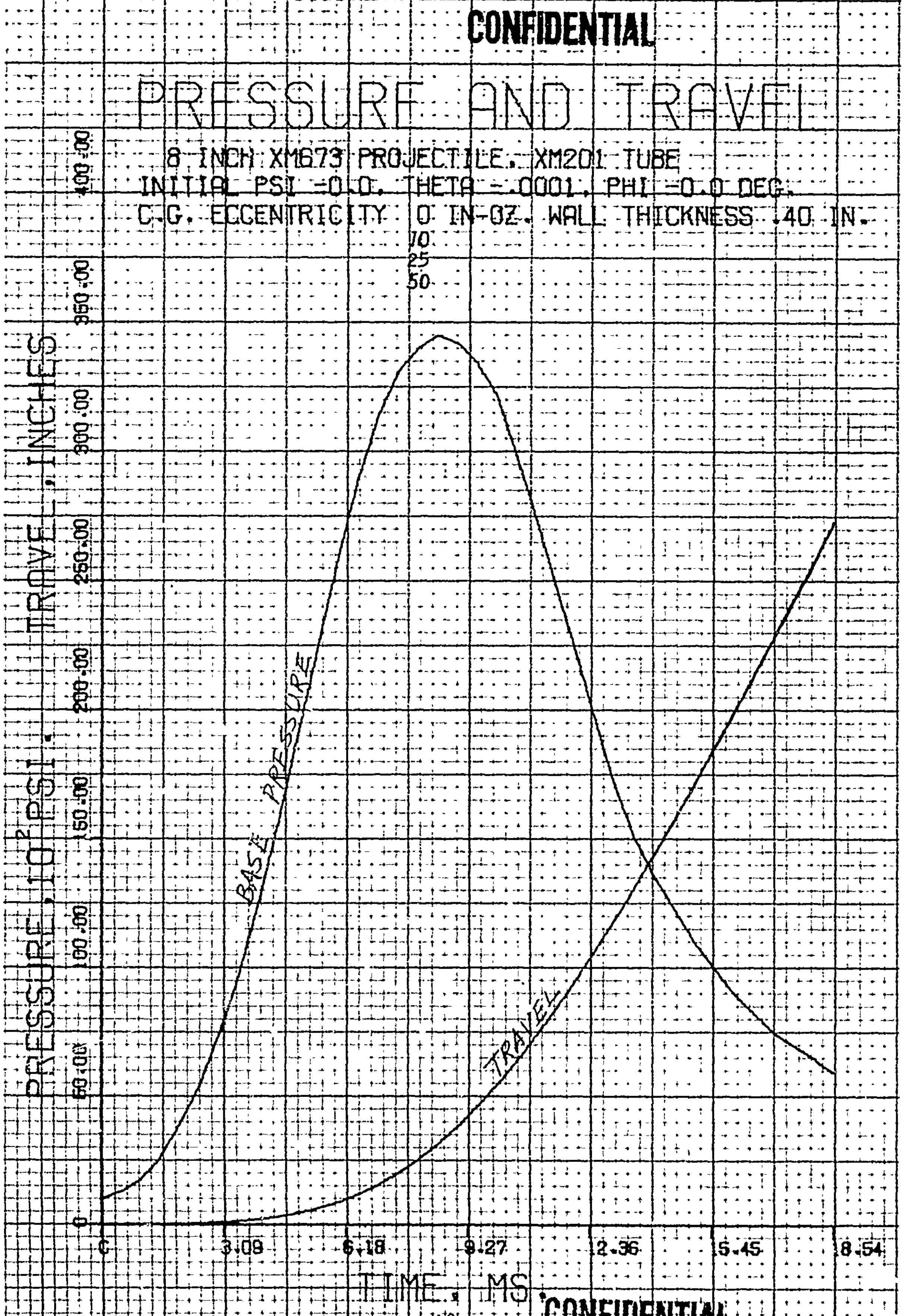
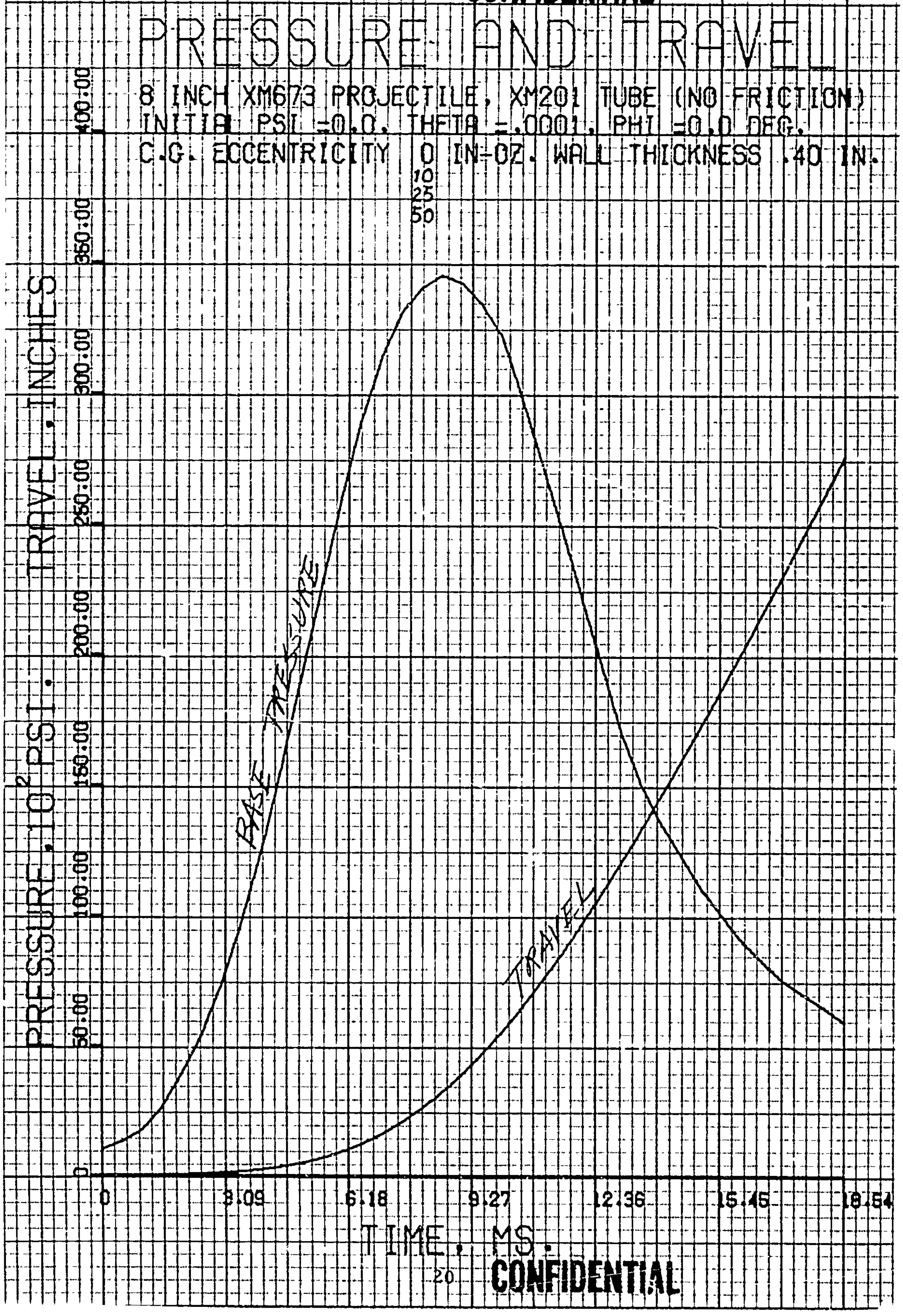
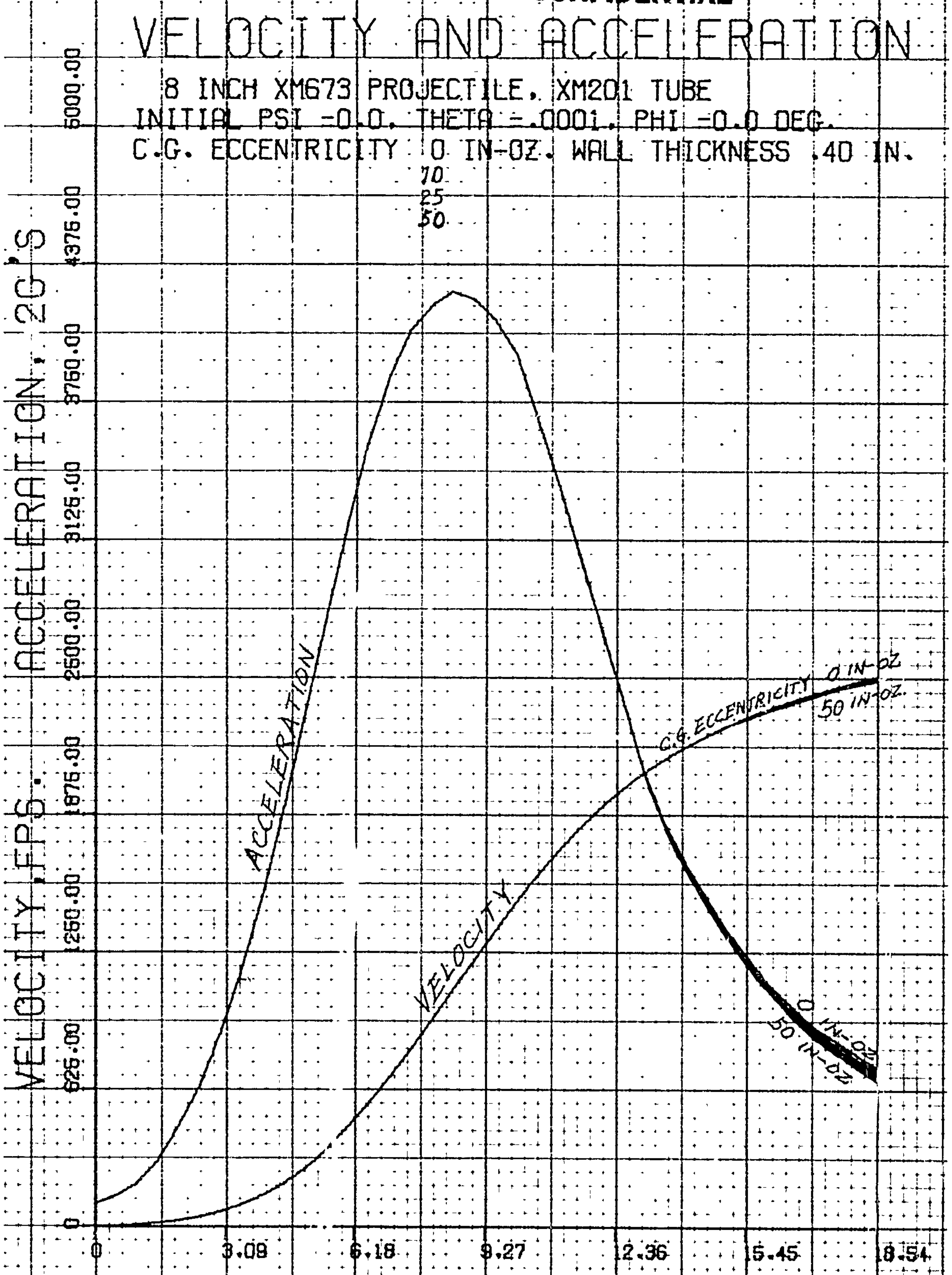

PRESSURE AND TRAVEL
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA = .0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ. WALL THICKNESS .40 IN.
70
25
50
PRESSURE,10² PSI • TRAVEL ,INCHES
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0
BASE PRESSURE
TRAVEL
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS

FIGURE 2b **CONFIDENTIAL**



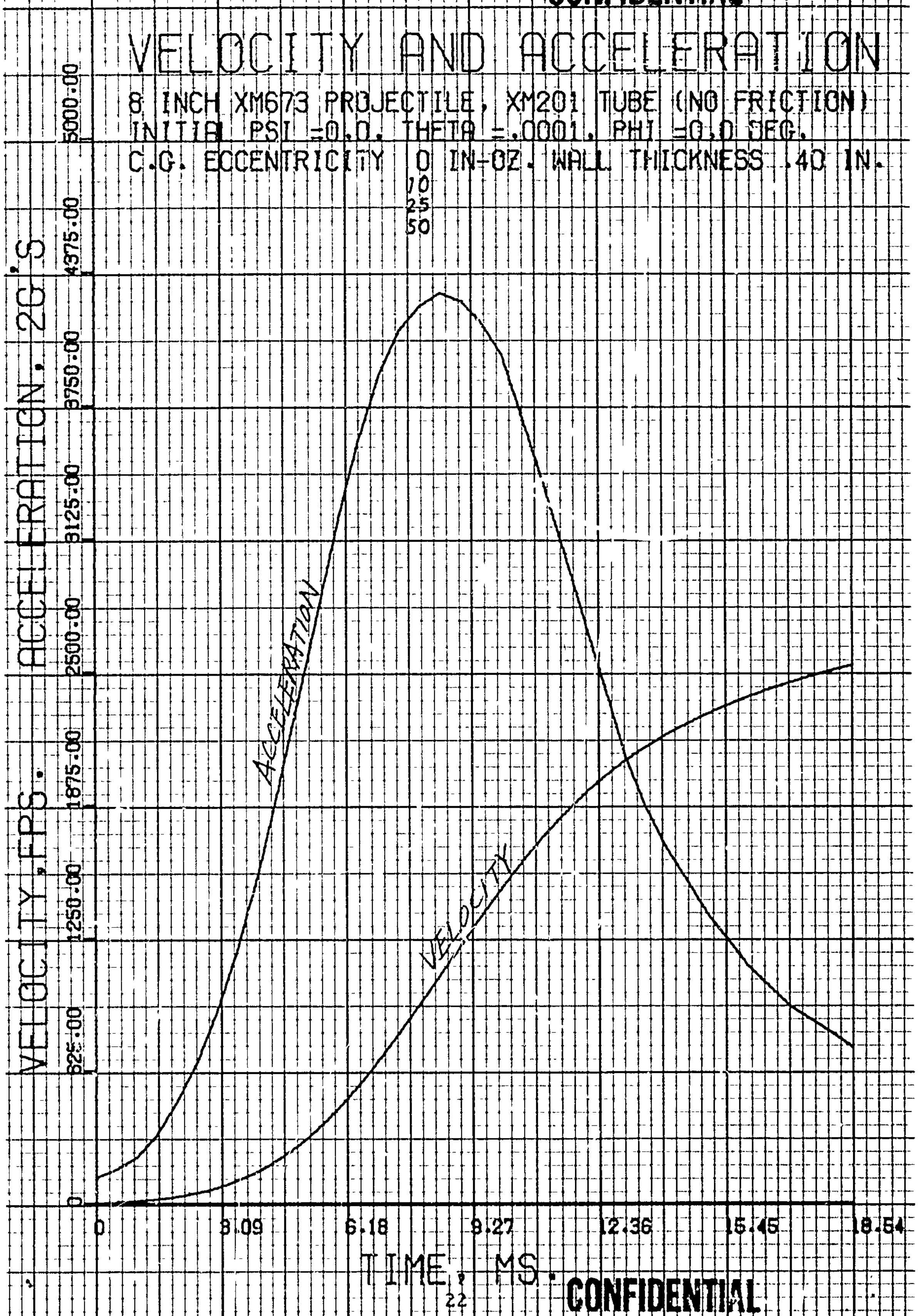
 CONFIDENTIAL

FIGURE 3a **CONFIDENTIAL**



CONFIDENTIAL

FIGURE 3b **CONFIDENTIAL**

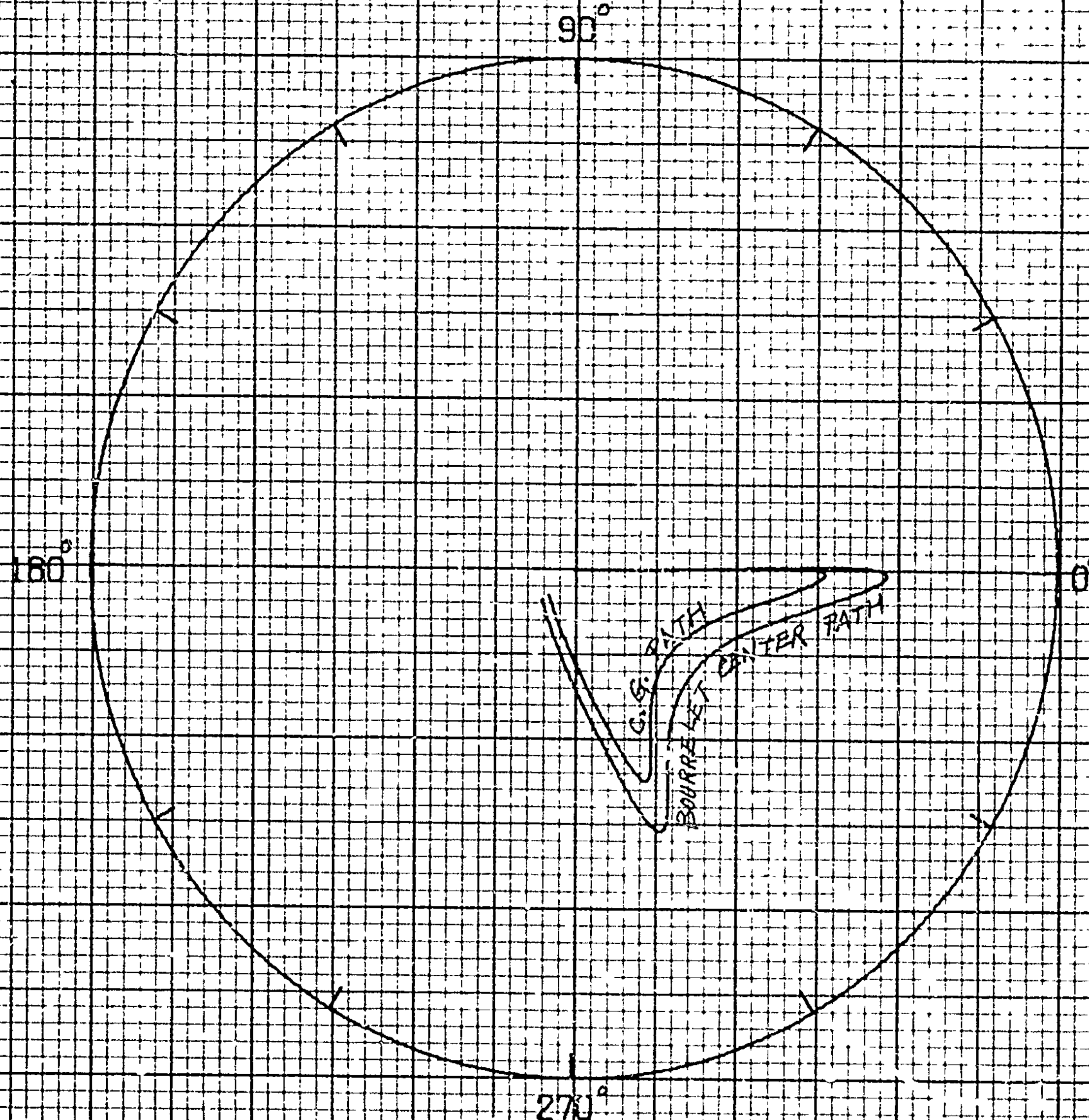


CONFIDENTIAL

FIGURE 4a

C.G. AND BOURRELET CENTER

8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ, WALL THICKNESS .40 IN.

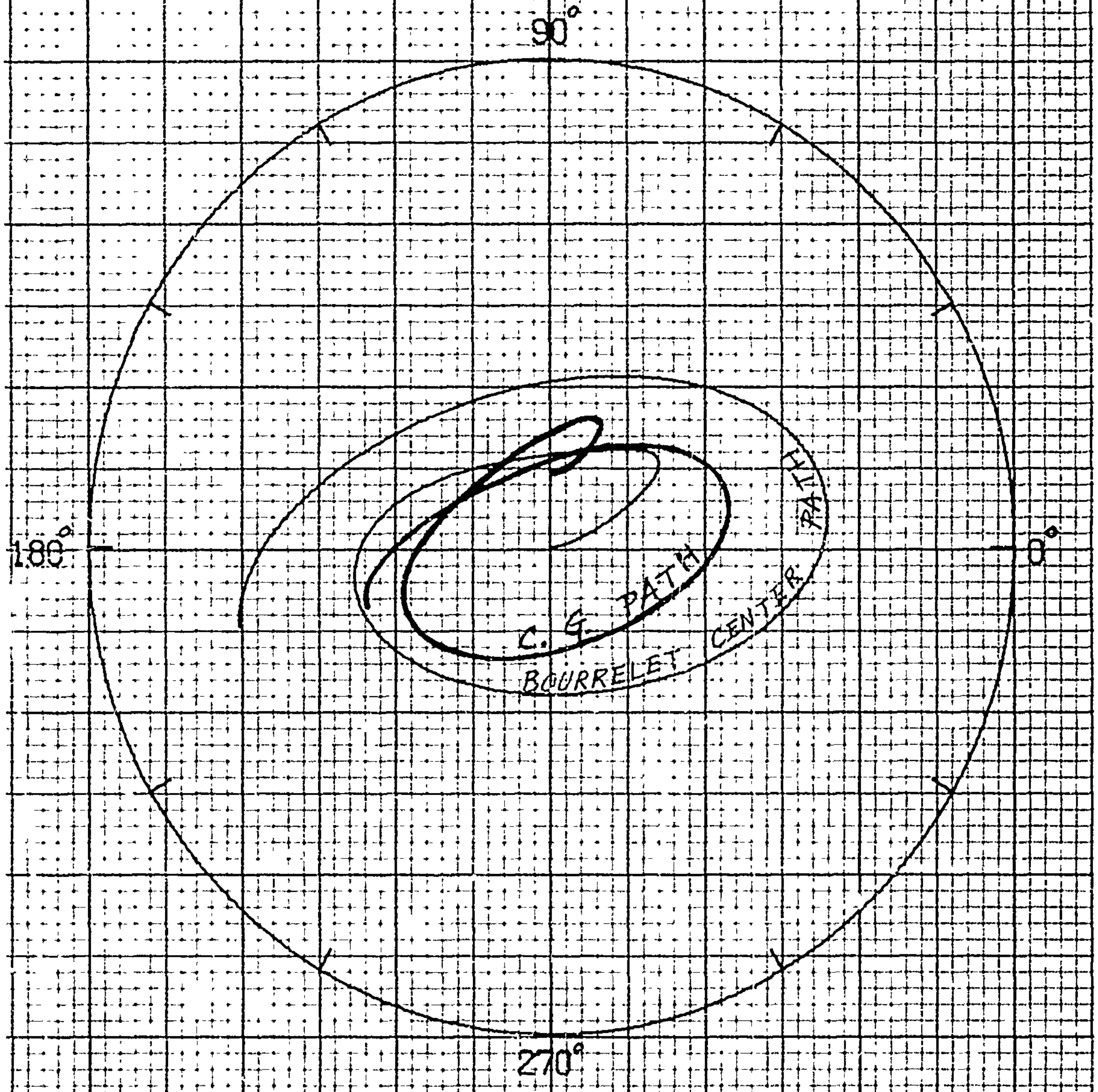


R= .0083 IN.

FIGURE 4b

C.G. AND BOURRELET CENTER

8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ. WALL THICKNESS .40 IN.

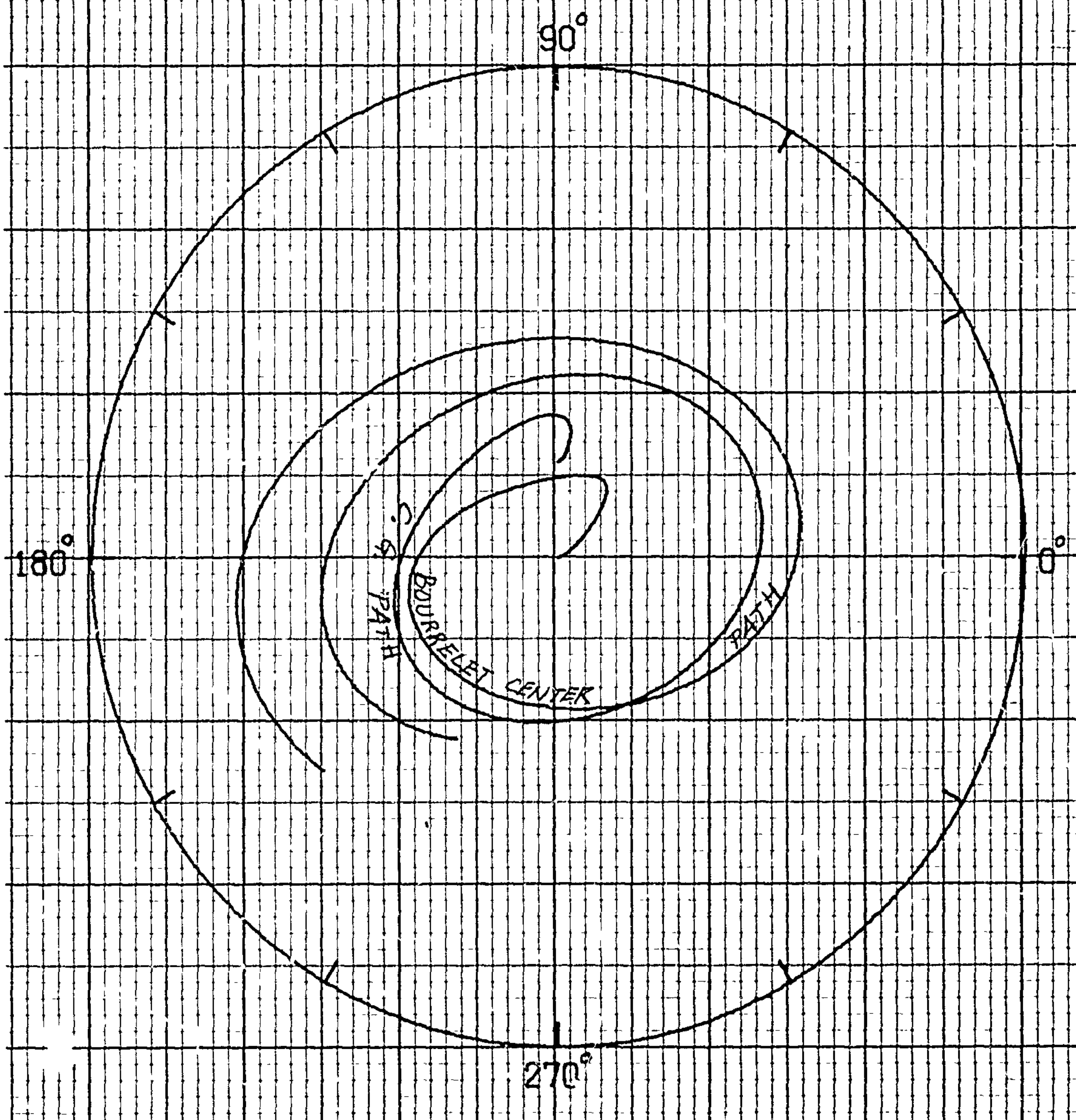


R= .0200 IN.

FIGURE 4c

C.G. AND BOURRELET CENTER

8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA = .0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ, WALL THICKNESS .40 IN.

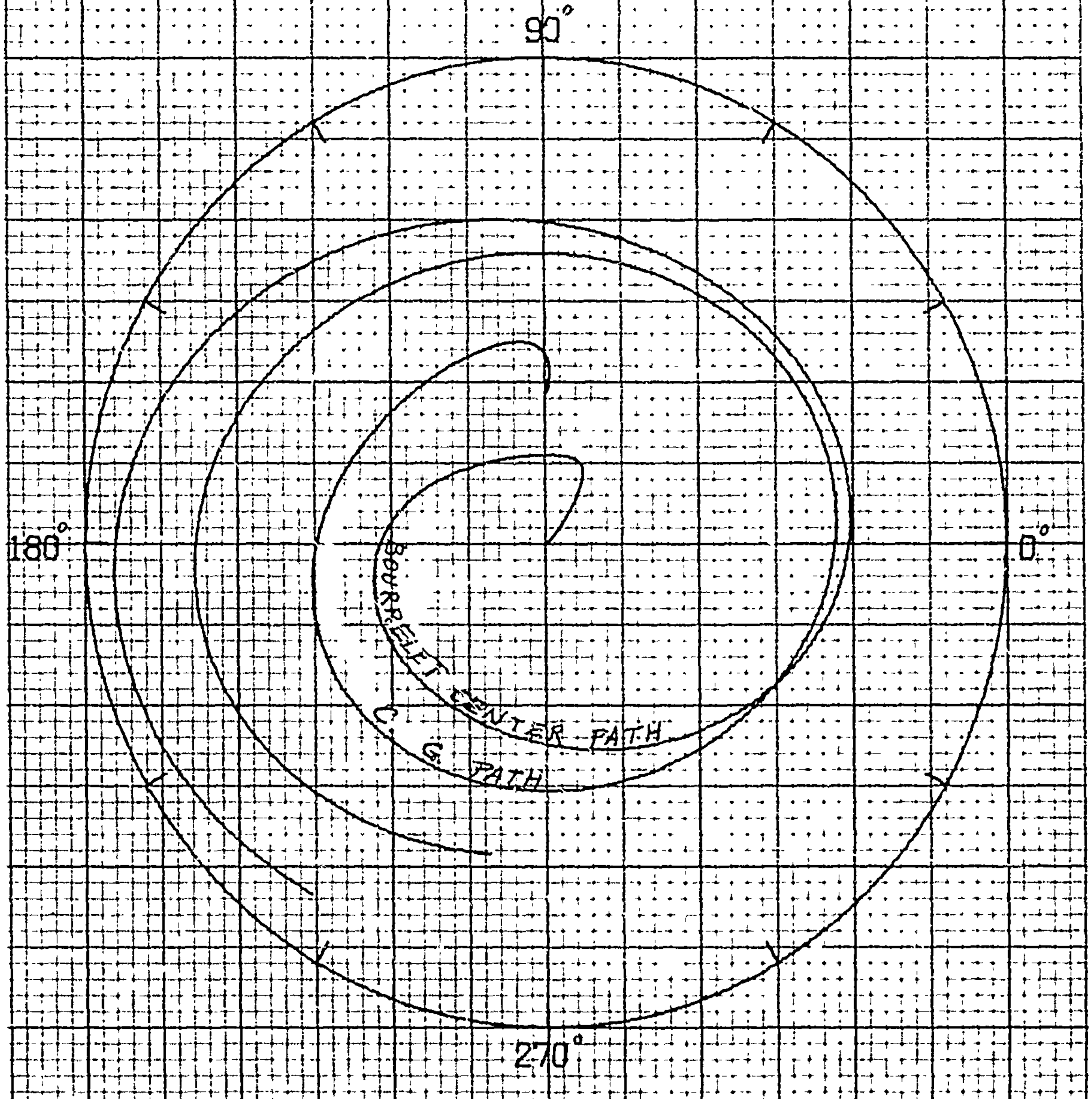


R= .0400 IN.

FIGURE 4d

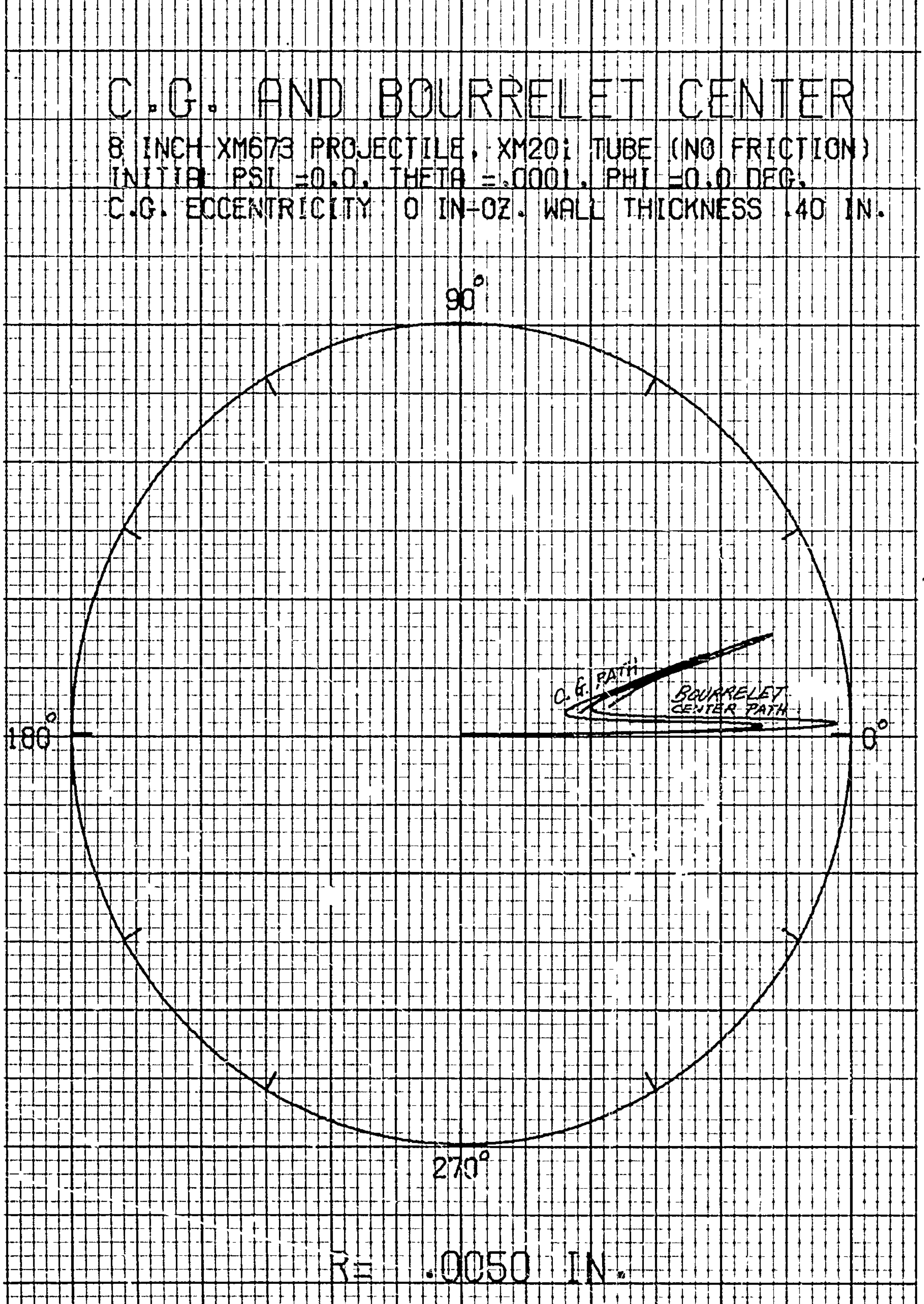
C.G. AND BOURRELET CENTER

8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ. WALL THICKNESS .40 IN.



R= .0500 IN.

FIGURE 5a

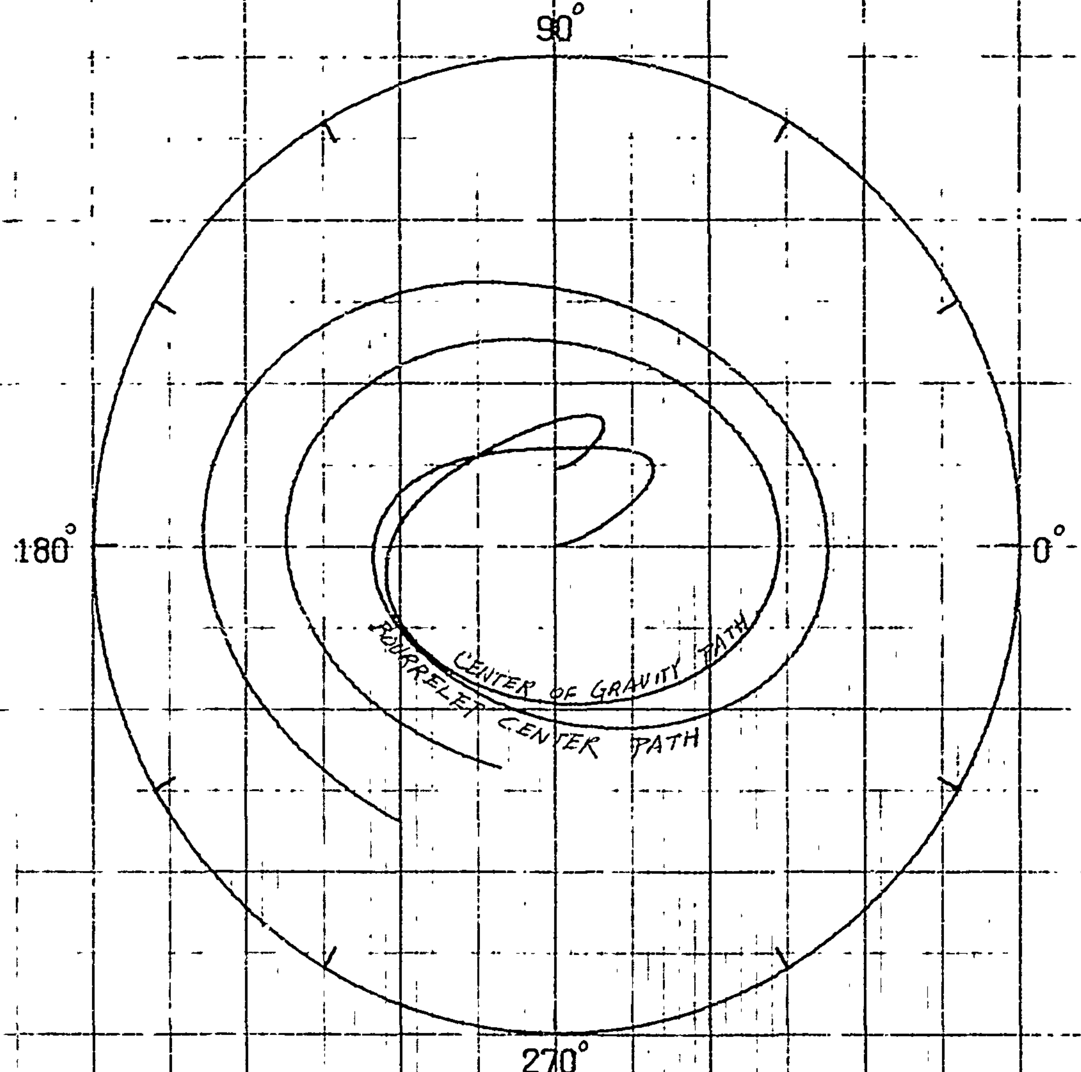


C.G. AND BOURRELET CENTER
8 INCH XM673 PROJECTILE, XM201 TUBE (NO FRICTION)
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ. WALL THICKNESS .40 IN.
90°
C.G. PATH
BOURRELET CENTER PATH
180°
0°
270°
R= .0050 IN.

FIGURE 5b

C.G. AND BOURRELET CENTER

8 INCH XM673 PROJECTILE, XM201 TUBE (NO FRICTION)
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ. WALL THICKNESS .40 IN.



R= .0200 IN.

FIGURE 5c

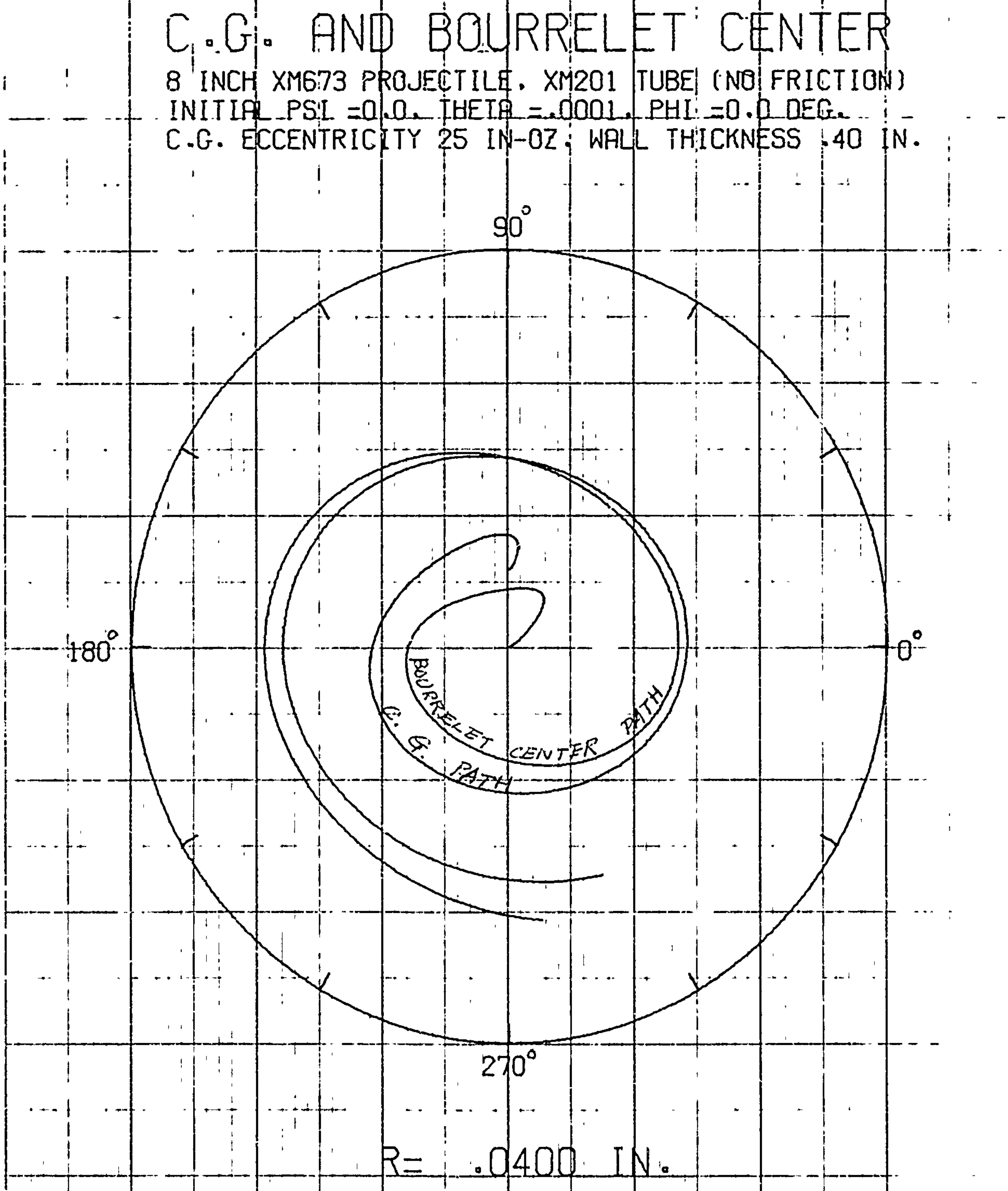

C.G. AND BOURRELET CENTER
8 INCH XM673 PROJECTILE, XM201 TUBE (NO FRICTION)
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ, WALL THICKNESS .40 IN.
90°
180°
0°
BOURRELET CENTER PATH
C. G. PATH
270°
R= .0400 IN.

FIGURE 5d

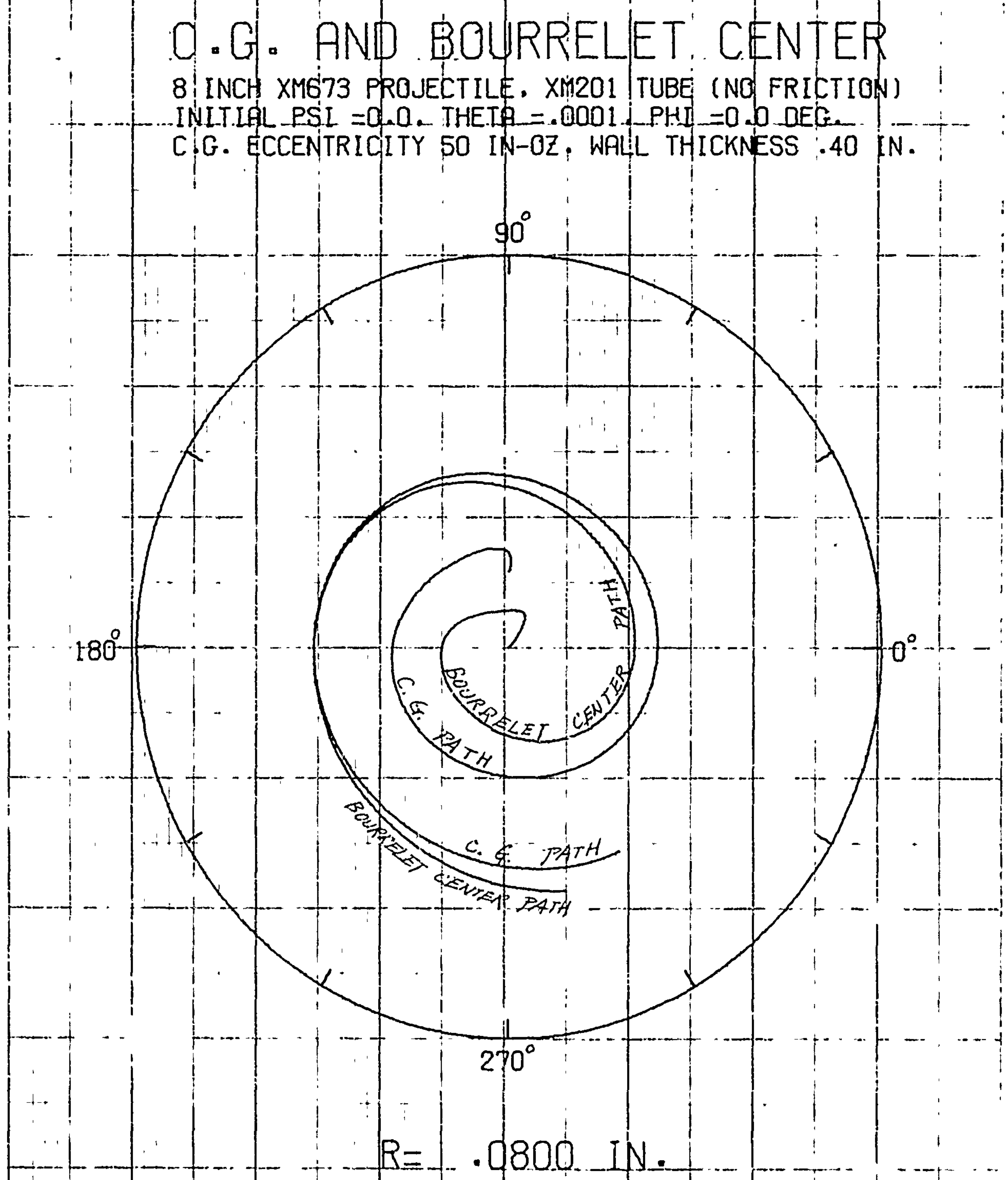

C.G. AND BOURRELET CENTER
8 INCH XM673 PROJECTILE, XM201 TUBE (NO FRICTION)
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ, WALL THICKNESS .40 IN.
90°
180°
0°
270°
BOURRELET CENTER PATH
C.G. PATH
C.G. PATH
BOURRELET CENTER PATH
R= .0800 IN.

FIGURE 6a

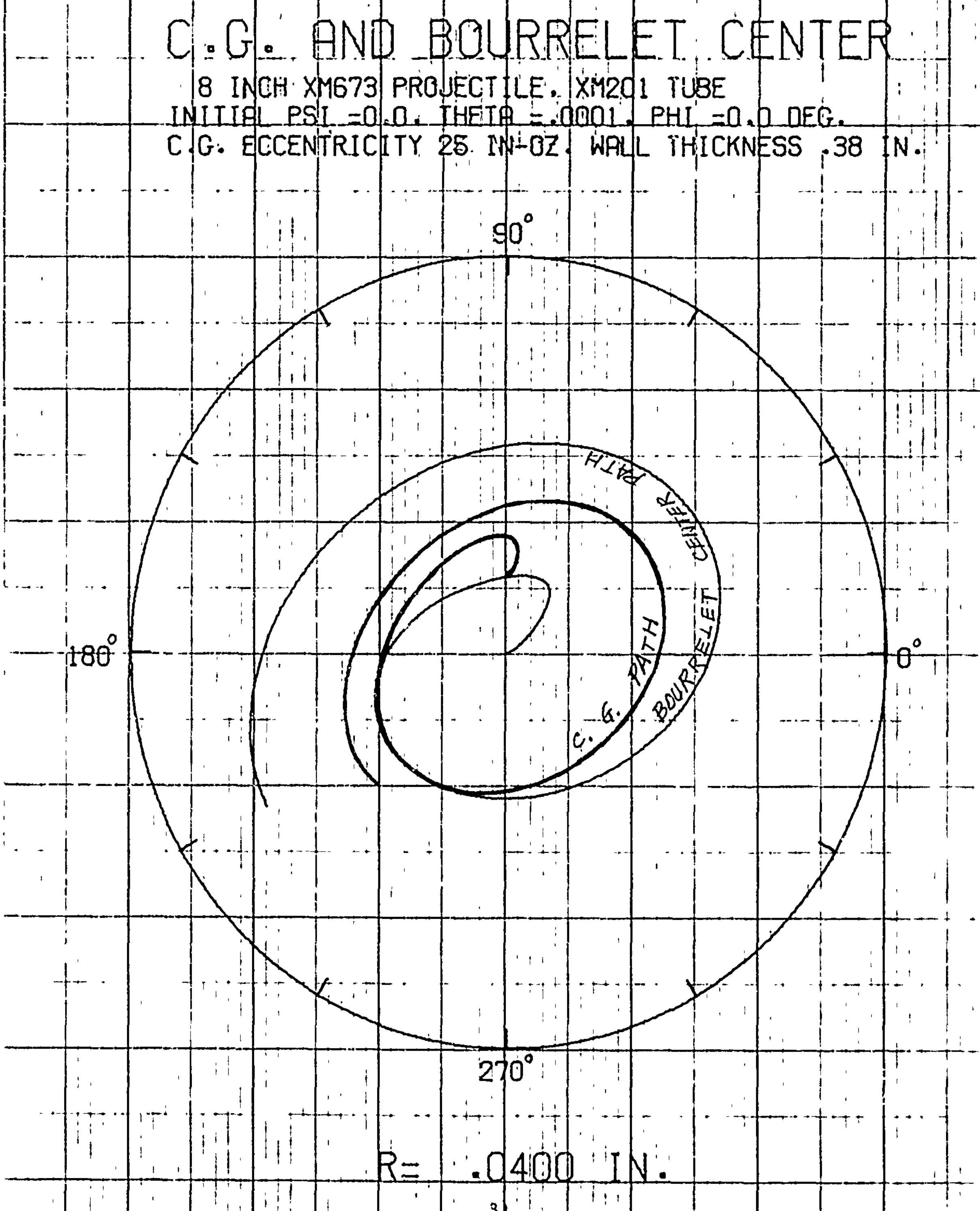

C.G. AND BOURRELET CENTER
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ, WALL THICKNESS .38 IN.
90°
180°
0°
270°
BOURRELET CENTER PATH
C. G. PATH
R= .0400 IN.

FIGURE 6b

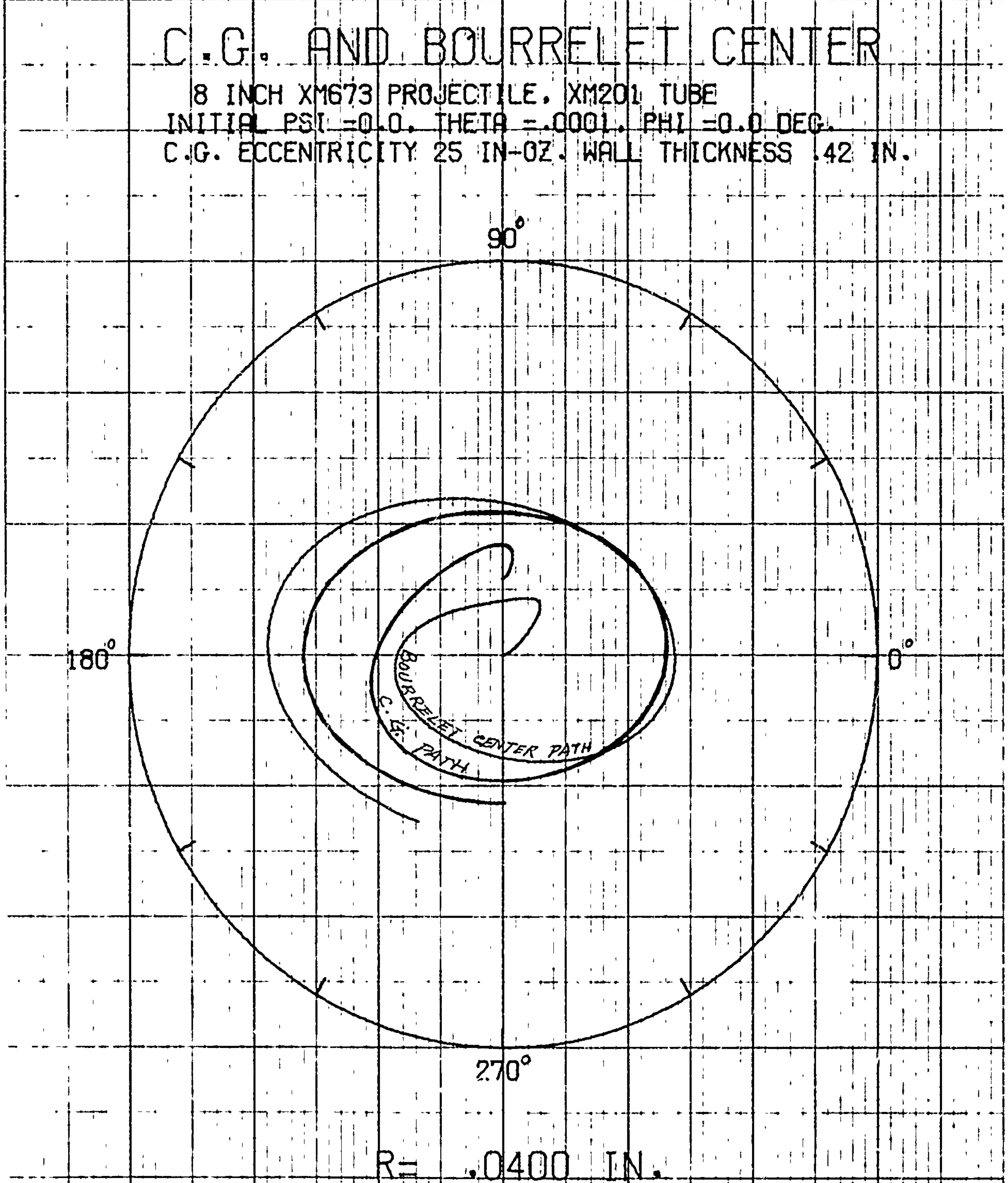

C.G. AND BOURRELET CENTER
8 INCH XM673 PROJECTILE. XM201 TUBE
INITIAL PSI =0.0. THETA =.0001. PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .42 IN.
90°
180°
0°
270°
BOURRELET CENTER PATH
C.G. PATH
R= .0400 IN.

FIGURE 7a

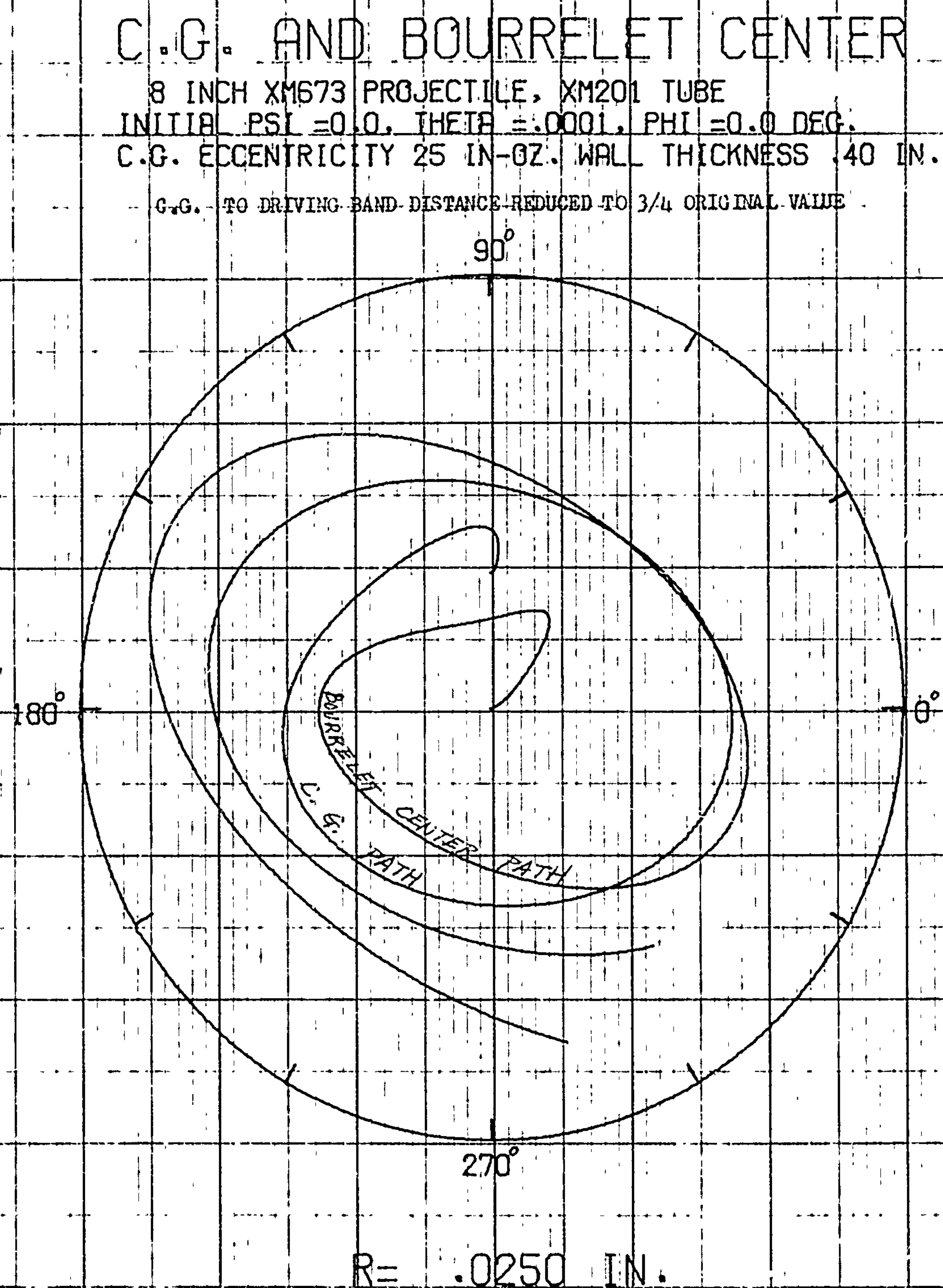
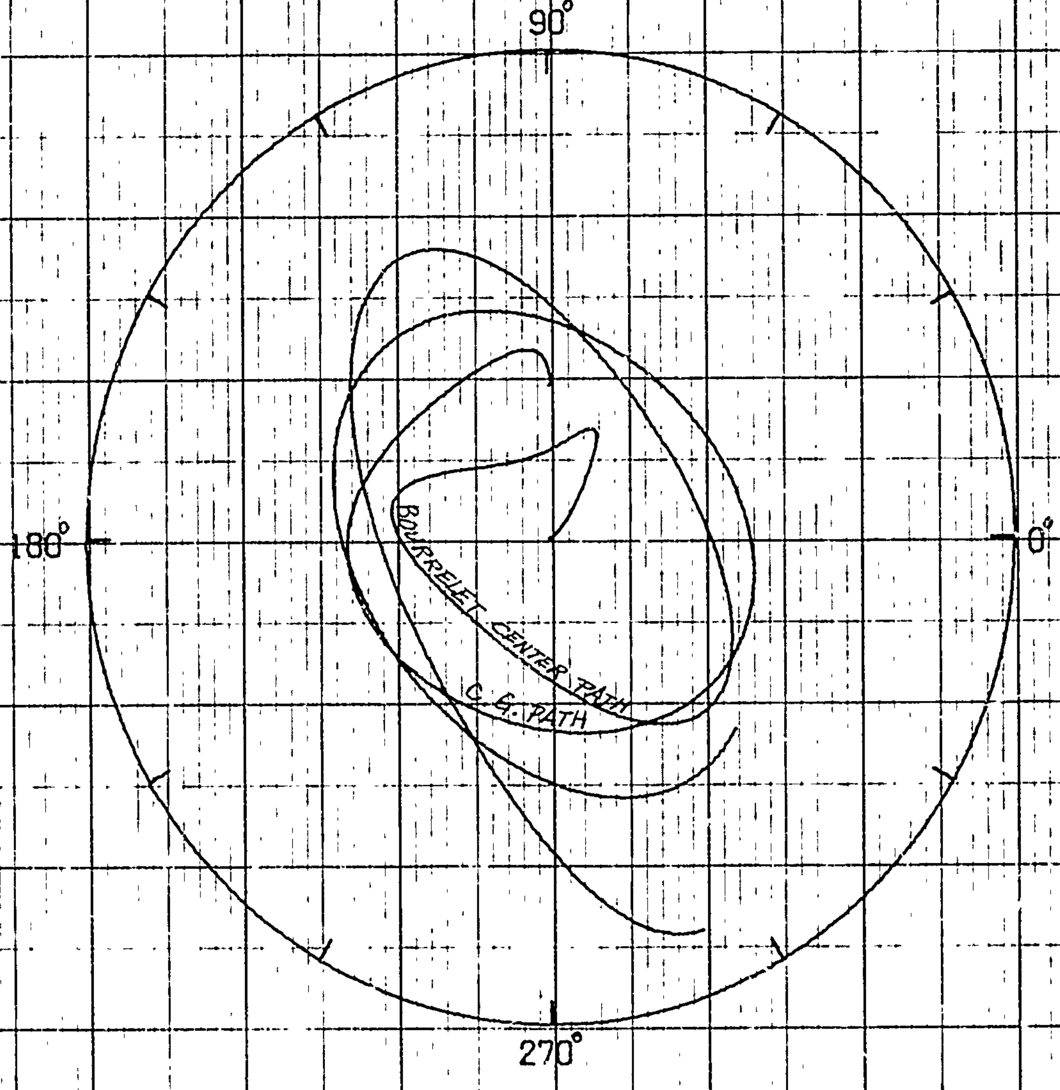

C.G. AND BOURRELET CENTER
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .40 IN.
C.G. TO DRIVING BAND DISTANCE REDUCED TO 3/4 ORIGINAL VALUE
90°
180°
0°
270°
BOURRELET CENTER PATH
C. G. PATH
R= .0250 IN.

FIGURE 7b

C.G. AND BOURRELET CENTER

8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .40 IN.

C.G. TO DRIVING BAND DISTANCE REDUCED TO ½ ORIGINAL VALUE



R= .0250 IN.

FIGURE 8a

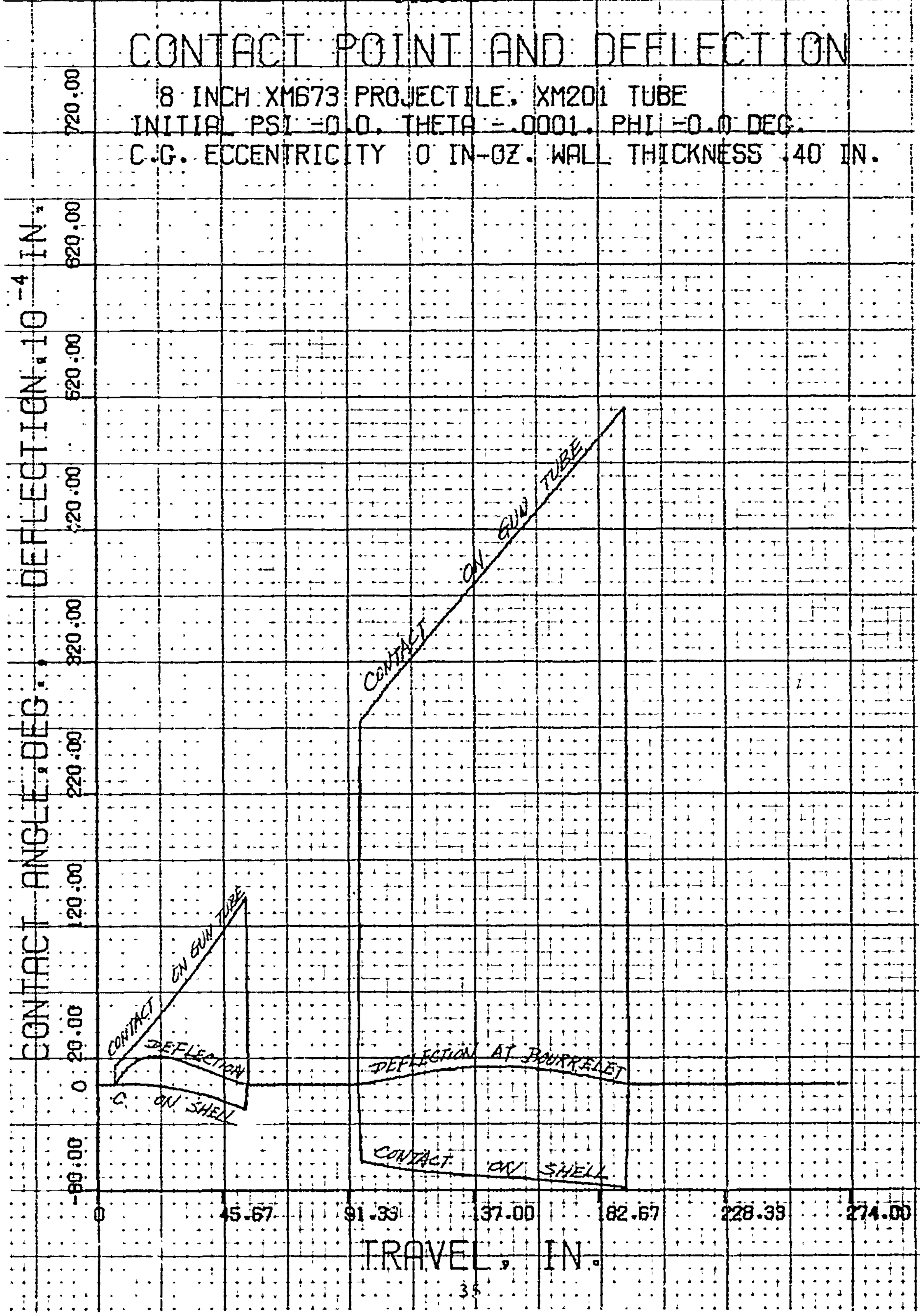

CONTACT POINT AND DEFLECTION
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ, WALL THICKNESS .40 IN.
CONTACT ANGLE, DEG., DEFLECTION, 10^-4 IN.
720.00
620.00
520.00
420.00
320.00
220.00
120.00
20.00
0
-80.00
0
45.67
91.33
137.00
182.67
228.33
274.00
TRAVEL, IN.
CONTACT ON GUN TUBE
DEFLECTION
C. ON SHELL
CONTACT ON GUN TUBE
DEFLECTION AT BOURRELET
CONTACT ON SHELL

FIGURE 8b

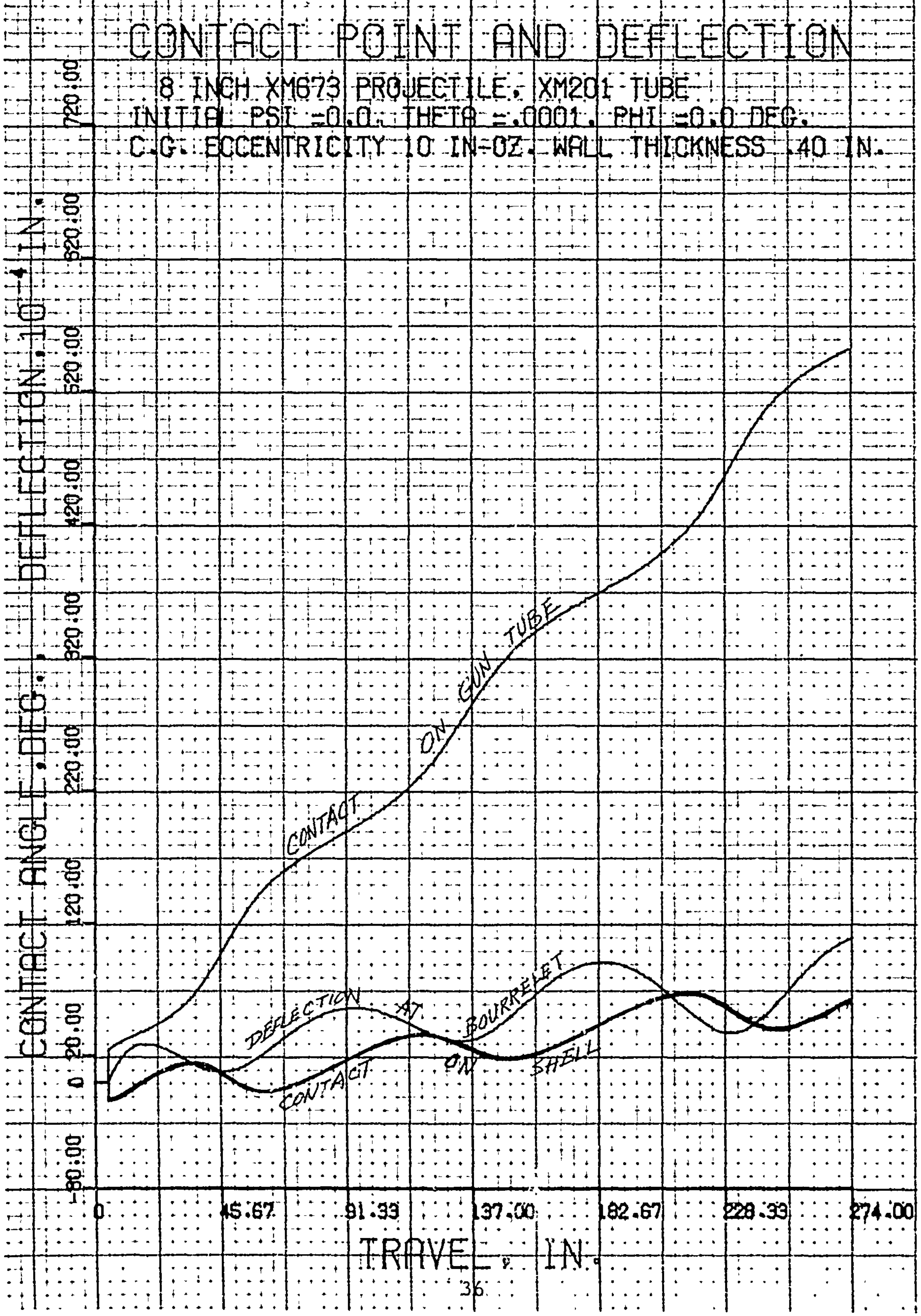

CONTACT POINT AND DEFLECTION
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ. WALL THICKNESS .40 IN.
CONTACT ANGLE,DEG., DEFLECTION,10-4 IN.
720.00
620.00
520.00
420.00
320.00
220.00
120.00
20.00
0
-80.00
0
45.67
91.33
137.00
182.67
228.33
274.00
TRAVEL, IN.
CONTACT ON GUN TUBE
DEFLECTION AT BOURRELET
CONTACT ON SHELL

FIGURE 8c

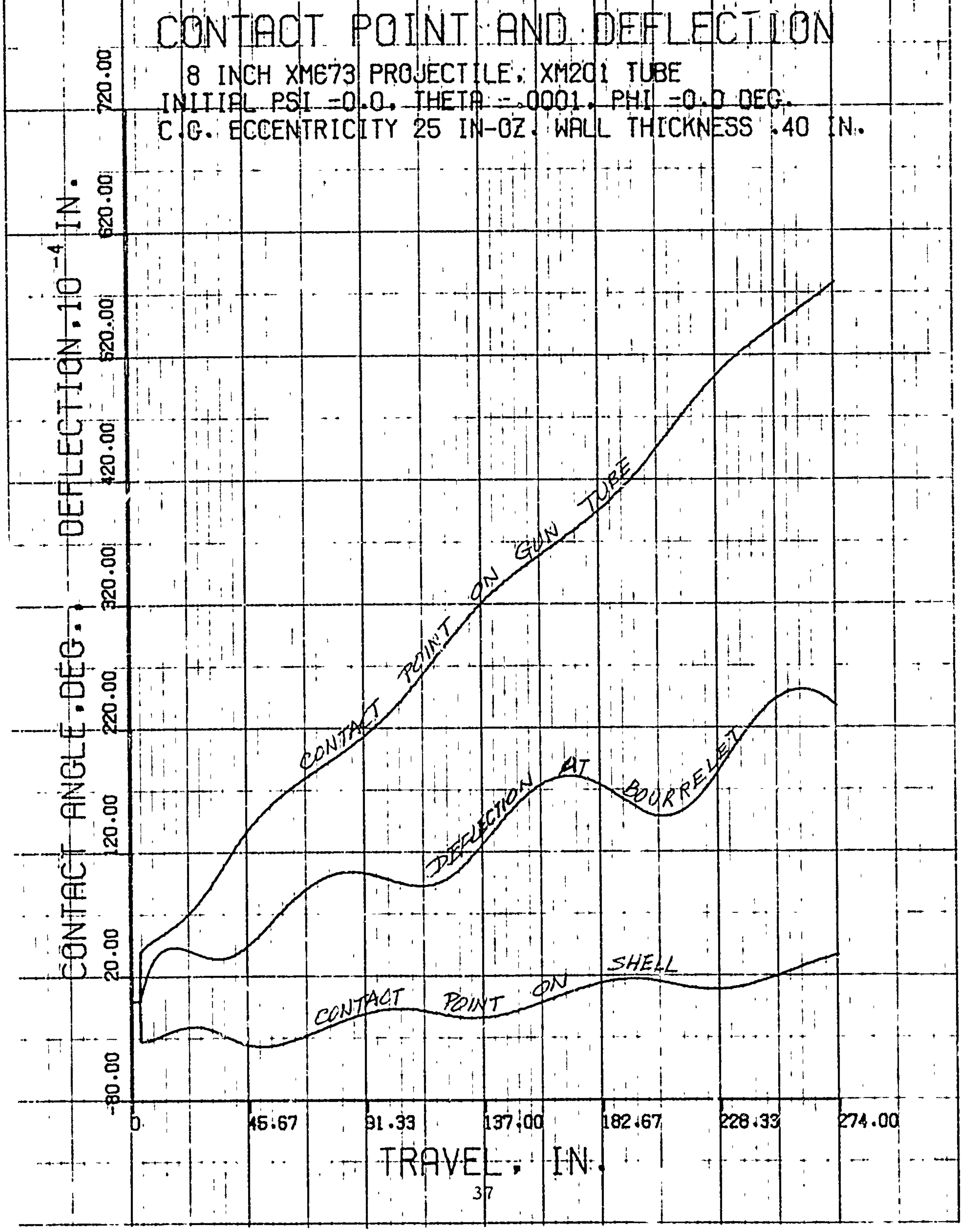

CONTACT POINT AND DEFLECTION
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ, WALL THICKNESS .40 IN.
CONTACT ANGLE,DEG., DEFLECTION,10^-4 IN.
720.00
620.00
520.00
420.00
320.00
220.00
120.00
20.00
-80.00
0
45.67
91.33
137.00
182.67
228.33
274.00
TRAVEL, IN.
CONTACT POINT ON GUN TUBE
DEFLECTION AT BOURRELET
CONTACT POINT ON SHELL

FIGURE 8d

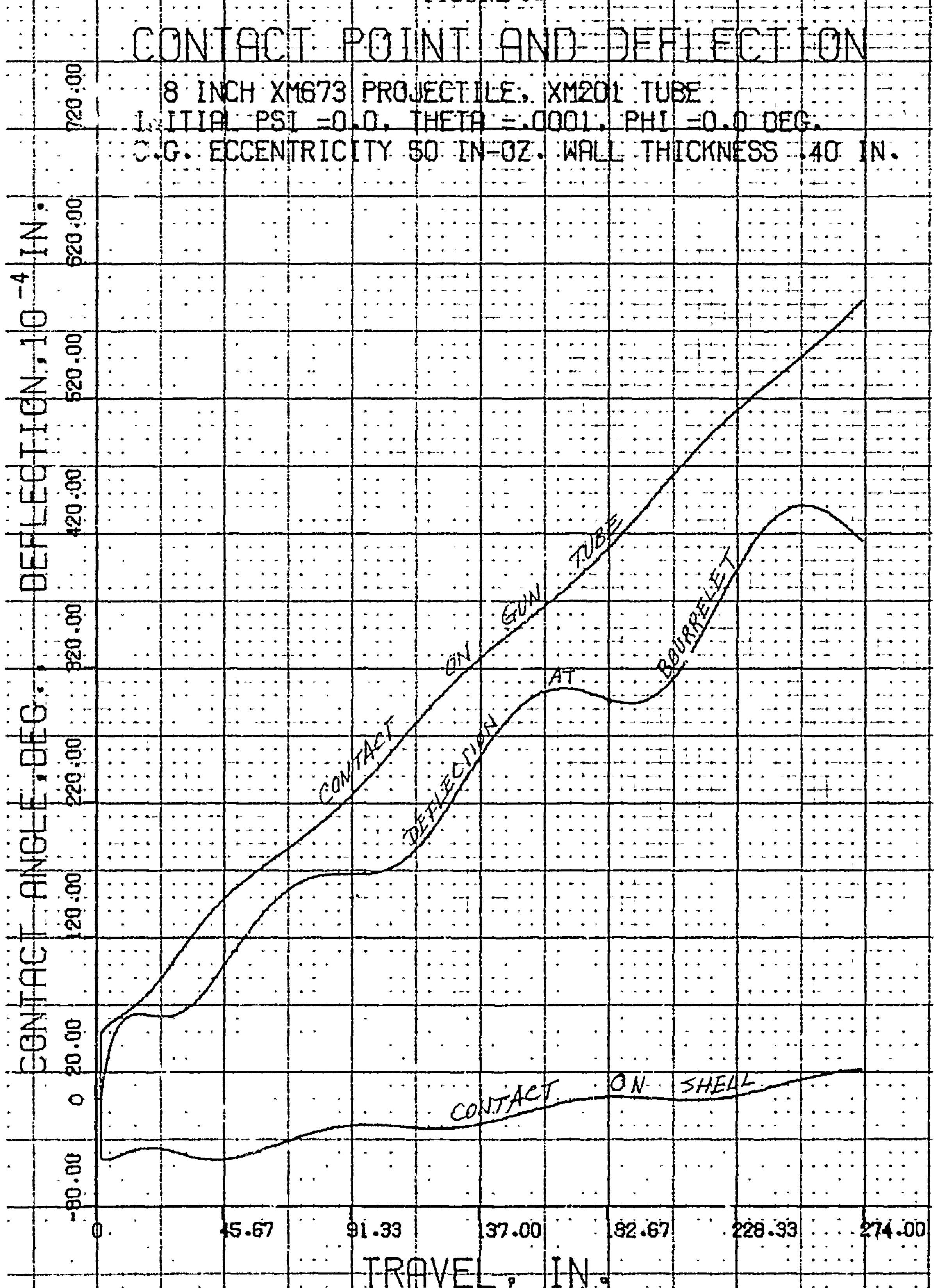

CONTACT POINT AND DEFLECTION
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ. WALL THICKNESS .40 IN.
CONTACT ANGLE, DEG., DEFLECTION, 10 -4 IN.
720.00
620.00
520.00
420.00
320.00
220.00
120.00
20.00
0
-80.00
0
45.67
91.33
137.00
182.67
228.33
274.00
TRAVEL, IN.
CONTACT ON GUN TUBE
DEFLECTION AT BOURRELET
CONTACT ON SHELL

FIGURE 9a

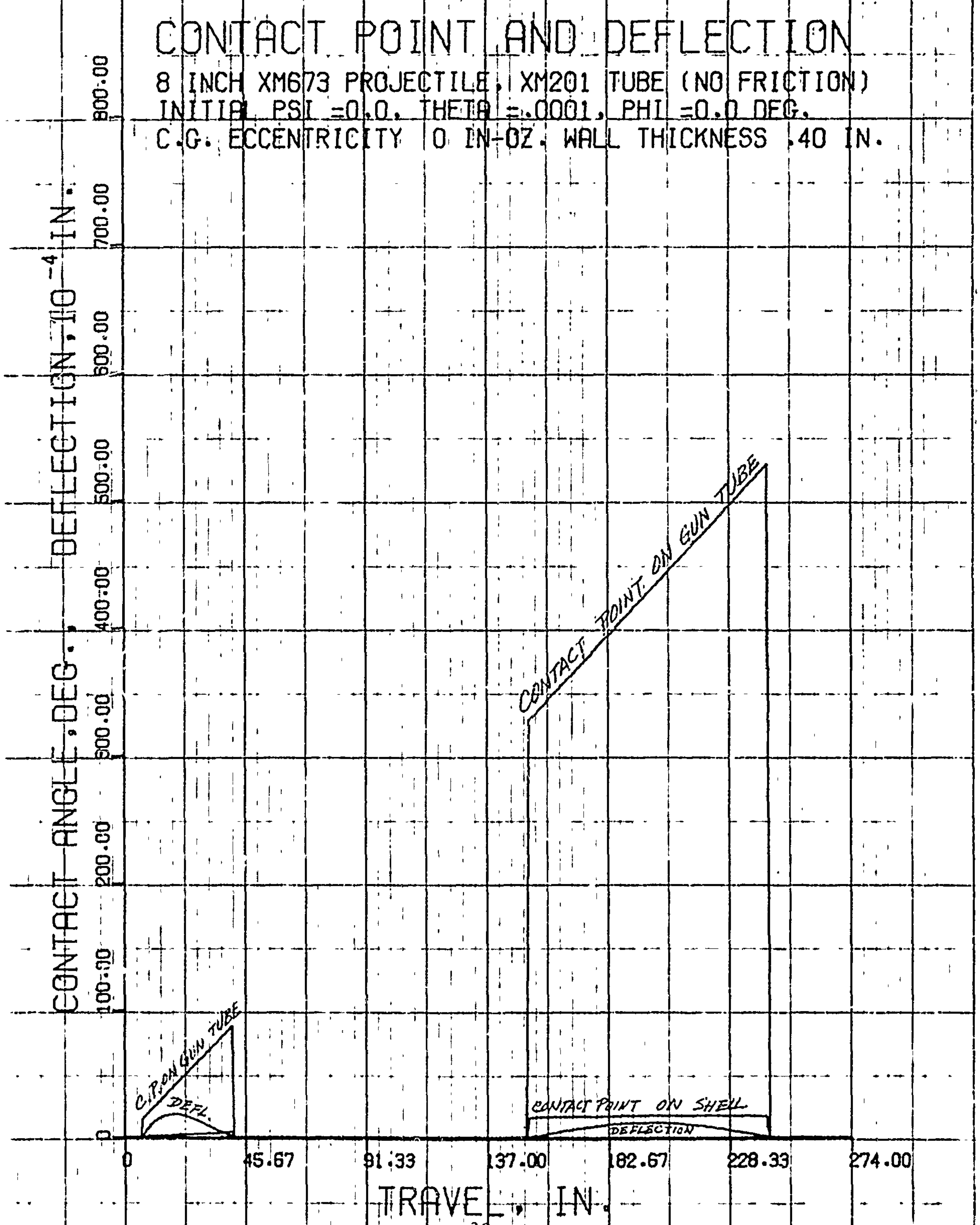

CONTACT POINT AND DEFLECTION
8 INCH XM673 PROJECTILE, XM201 TUBE (NO FRICTION)
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ. WALL THICKNESS .40 IN.
CONTACT ANGLE, DEG., DEFLECTION, 10^-4 IN.
0
100.00
200.00
300.00
400.00
500.00
600.00
700.00
800.00
C.P. ON GUN TUBE
DEFL.
CONTACT POINT ON GUN TUBE
CONTACT POINT ON SHELL
DEFLECTION
0
45.67
91.33
137.00
182.67
228.33
274.00
TRAVEL, IN.

FIGURE 9b

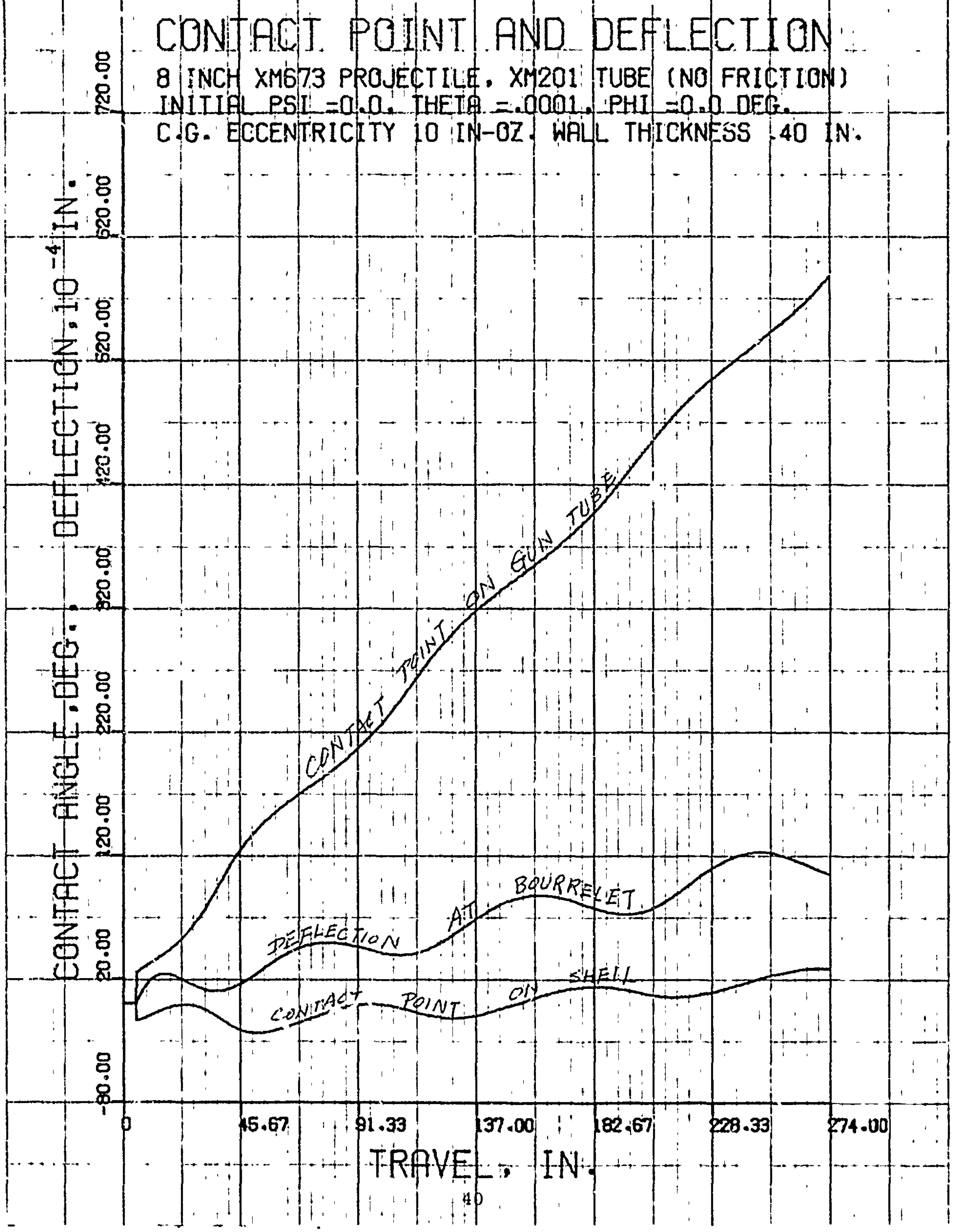

CONTACT POINT AND DEFLECTION
8 INCH XM673 PROJECTILE, XM201 TUBE (NO FRICTION)
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ, WALL THICKNESS .40 IN.
CONTACT ANGLE, DEG., DEFLECTION, 10⁻⁴ IN.
720.00
620.00
520.00
420.00
320.00
220.00
120.00
20.00
-80.00
CONTACT POINT ON GUN TUBE
DEFLECTION AT BOURRELET
CONTACT POINT ON SHELL
0
45.67
91.33
137.00
182.67
228.33
274.00
TRAVEL, IN.

FIGURE 9c

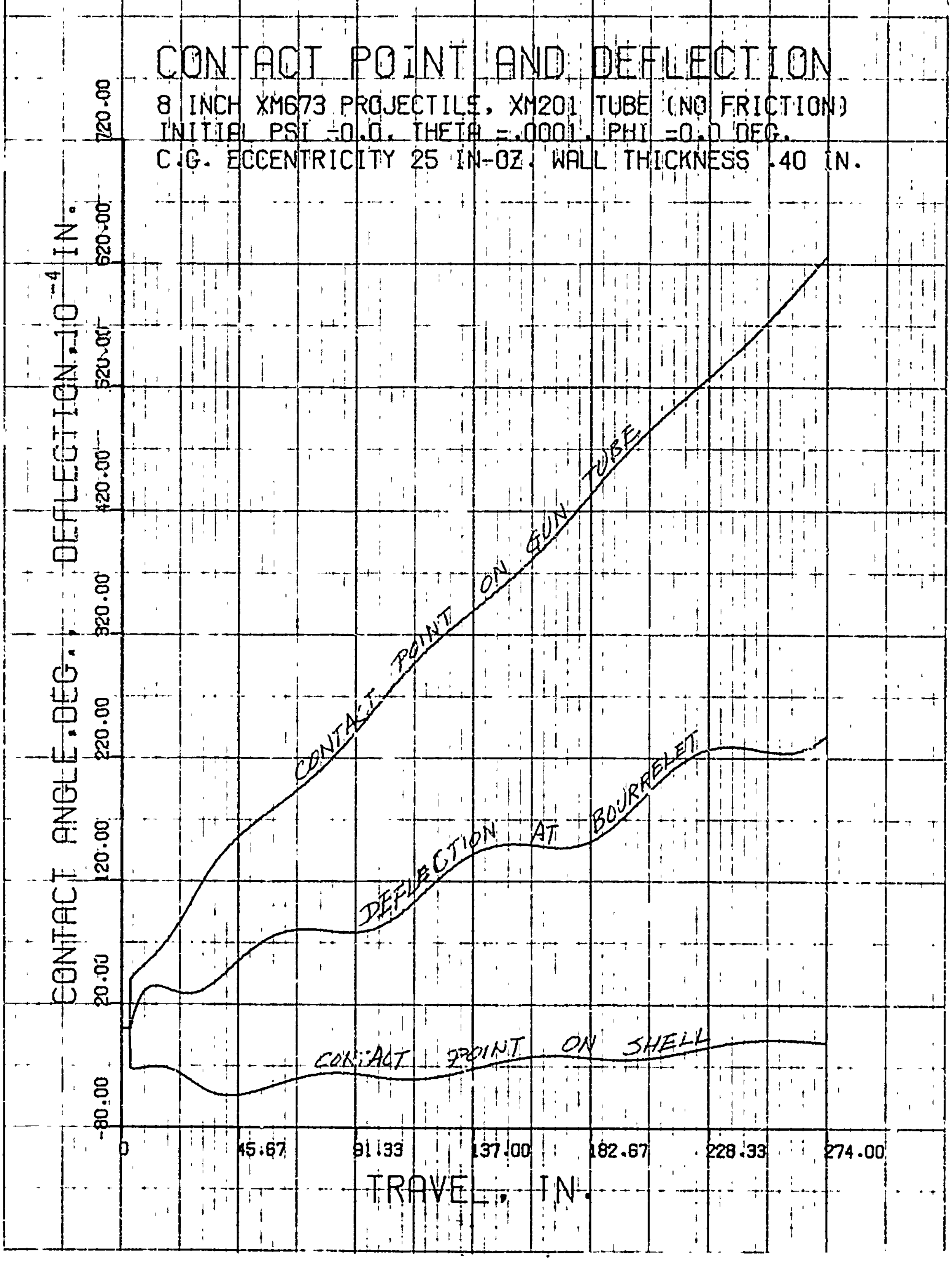
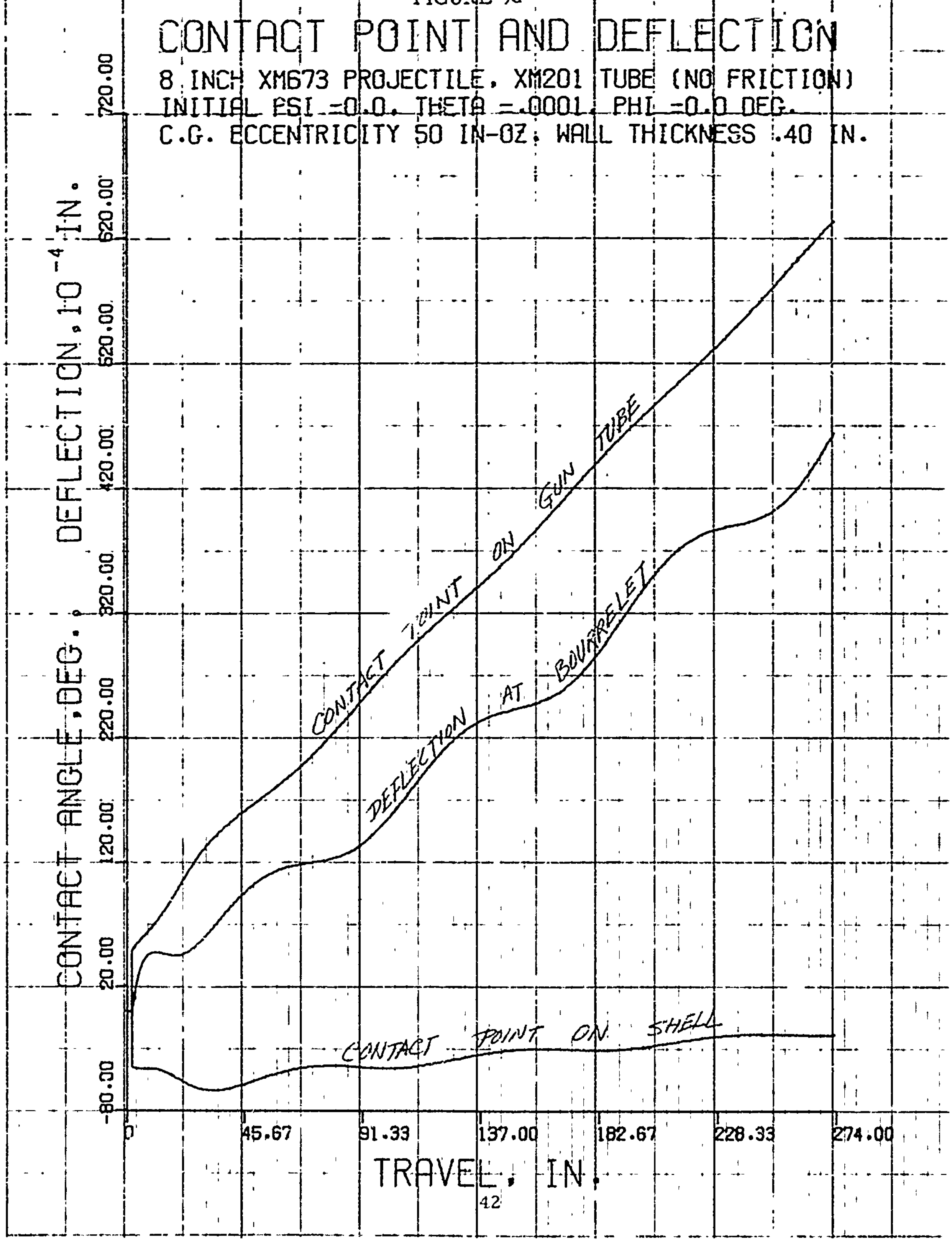
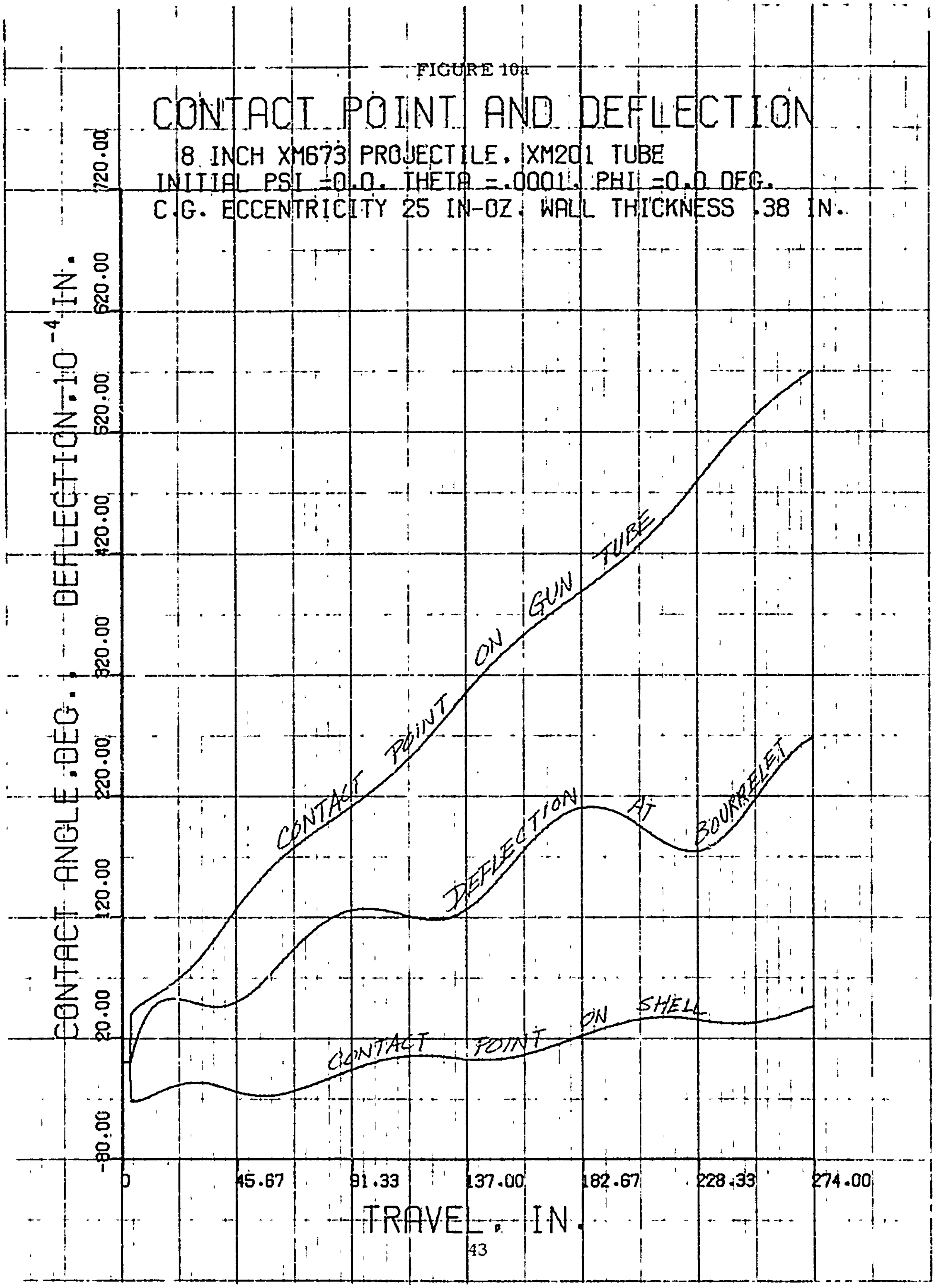

CONTACT POINT AND DEFLECTION
8 INCH XM673 PROJECTILS, XM201 TUBE (NO FRICTION)
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .40 IN.
CONTACT ANGLE, DEG., DEFLECTION, 10^{-4} IN.
720.00
620.00
520.00
420.00
320.00
220.00
120.00
20.00
-80.00
0
45.67
91.33
137.00
182.67
228.33
274.00
TRAVEL, IN.
CONTACT POINT ON GUN TUBE
DEFLECTION AT BOURRELET
CONTACT POINT ON SHELL

FIGURE 9d



CONTACT POINT AND DEFLECTION
8 INCH XM673 PROJECTILE, XM201 TUBE (NO FRICTION)
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ, WALL THICKNESS .40 IN.
CONTACT ANGLE,DEG., DEFLECTION,10^-4 IN.
720.00
620.00
520.00
420.00
320.00
220.00
120.00
20.00
-80.00
0
45.67
91.33
137.00
182.67
228.33
274.00
TRAVEL, IN.
CONTACT POINT ON GUN TUBE
DEFLECTION AT BOURRELET
CONTACT POINT ON SHELL

FIGURE 10a



CONTACT POINT AND DEFLECTION
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ, WALL THICKNESS .38 IN.
CONTACT ANGLE,DEG., DEFLECTION,10^{-4} IN.
720.00
620.00
520.00
420.00
320.00
220.00
120.00
20.00
-80.00
0
45.67
91.33
137.00
182.67
228.33
274.00
TRAVEL, IN.
CONTACT POINT ON GUN TUBE
DEFLECTION AT BOURRELET
CONTACT POINT ON SHELL

FIGURE 10b

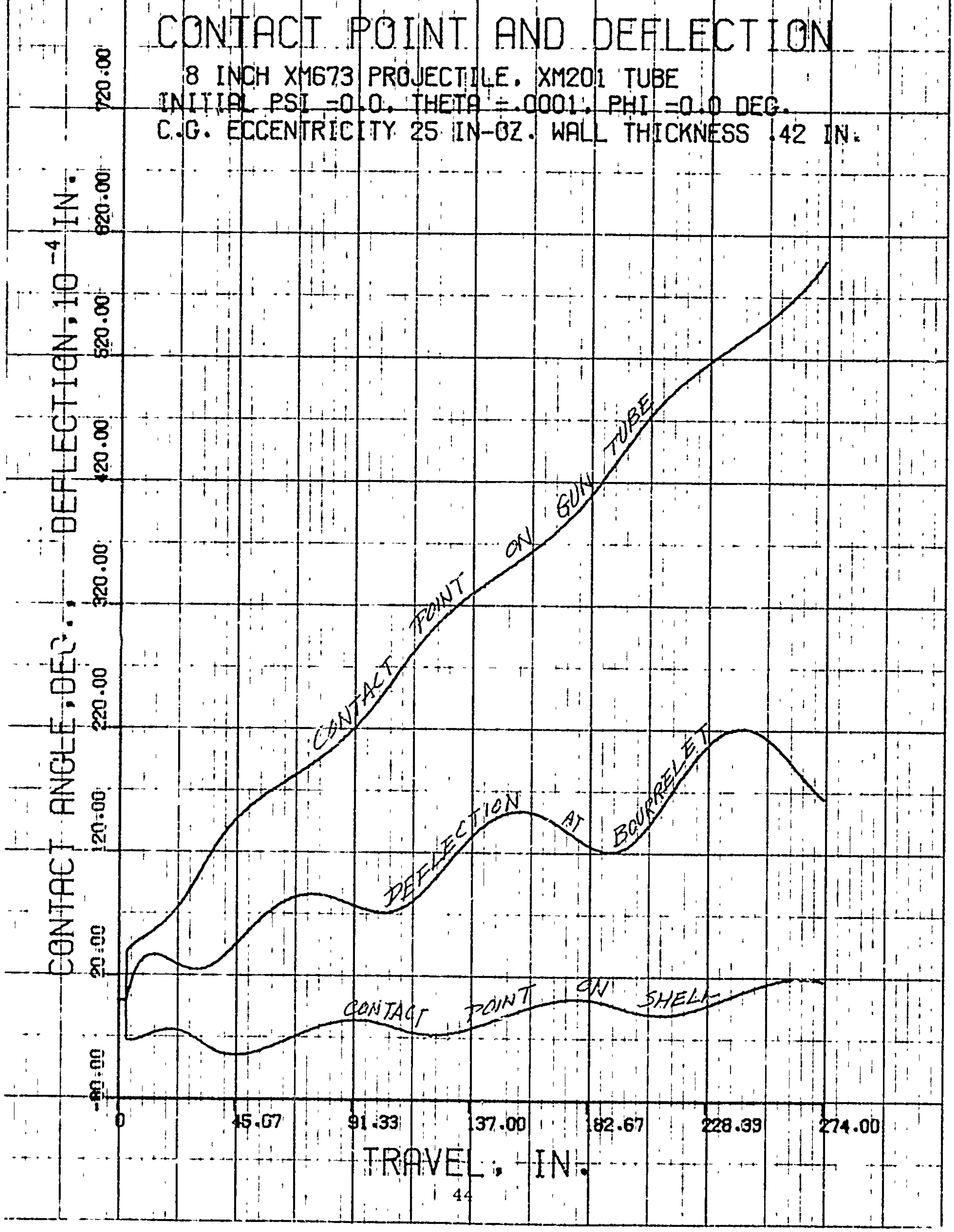
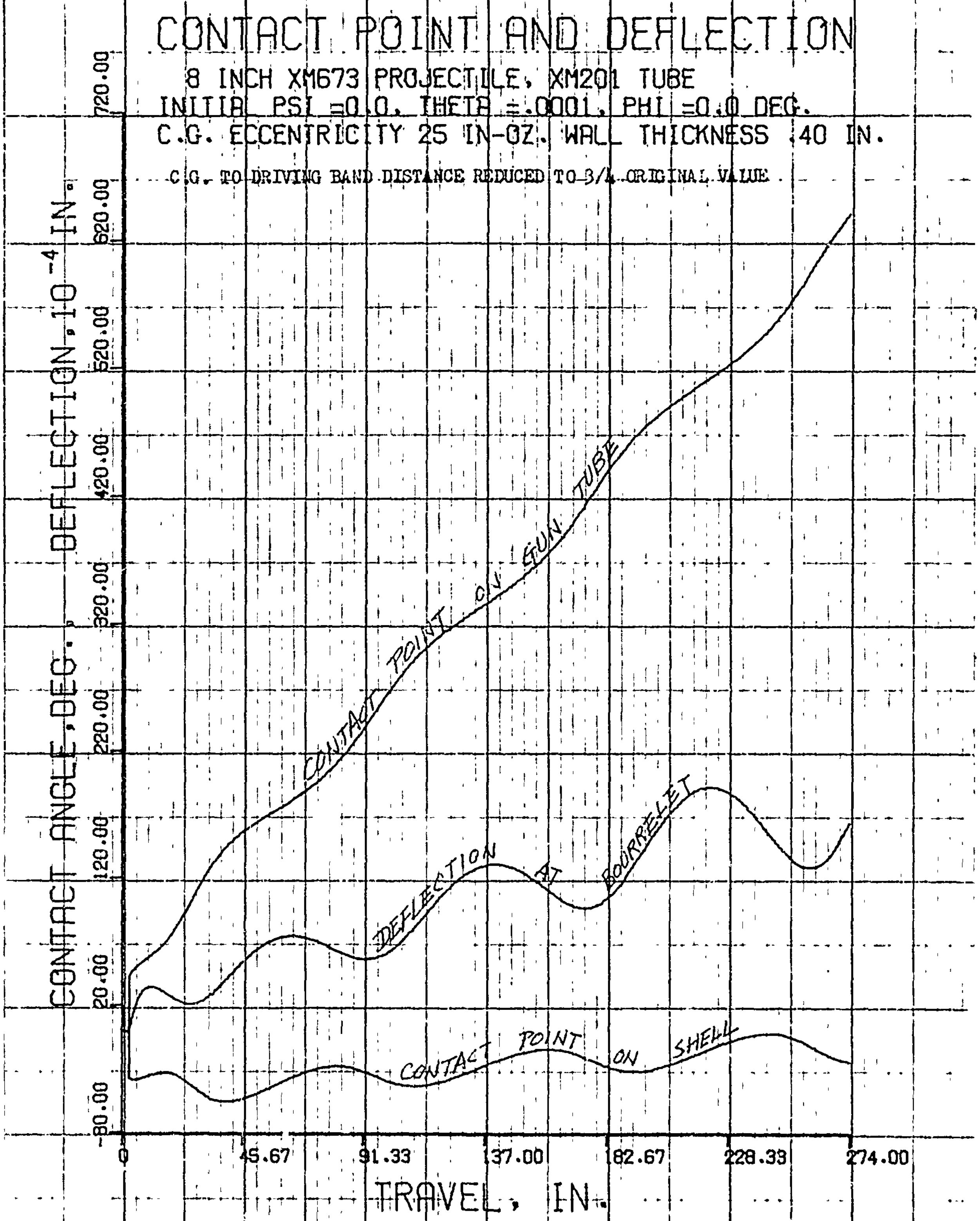

CONTACT POINT AND DEFLECTION
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .42 IN.
CONTACT ANGLE,DEG., DEFLECTION,10^-4 IN.
720.00
620.00
520.00
420.00
320.00
220.00
120.00
20.00
-80.00
0
45.67
91.33
137.00
182.67
228.33
274.00
TRAVEL, IN.
CONTACT POINT ON GUN TUBE
DEFLECTION AT BOURRELET
CONTACT POINT ON SHELL

FIGURE 11a



CONTACT POINT AND DEFLECTION
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .40 IN.
C.G. TO DRIVING BAND DISTANCE REDUCED TO 3/4 ORIGINAL VALUE
CONTACT ANGLE,DEG., DEFLECTION,10^-4 IN.
720.00
620.00
520.00
420.00
320.00
220.00
120.00
20.00
-80.00
0
45.67
91.33
137.00
182.67
228.33
274.00
TRAVEL, IN.
CONTACT POINT ON GUN TUBE
DEFLECTION AT BOURRELET
CONTACT POINT ON SHELL

FIGURE 11b

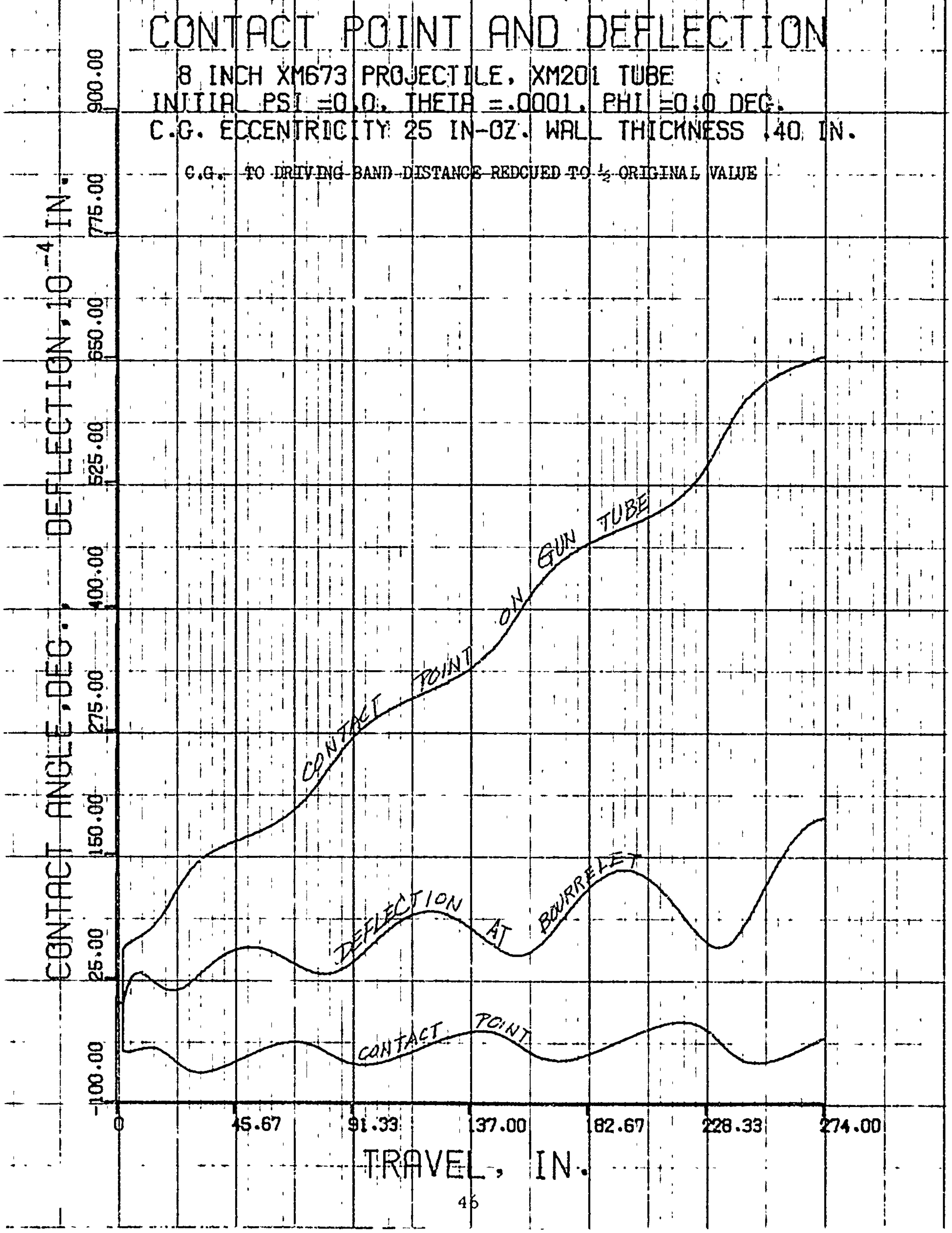
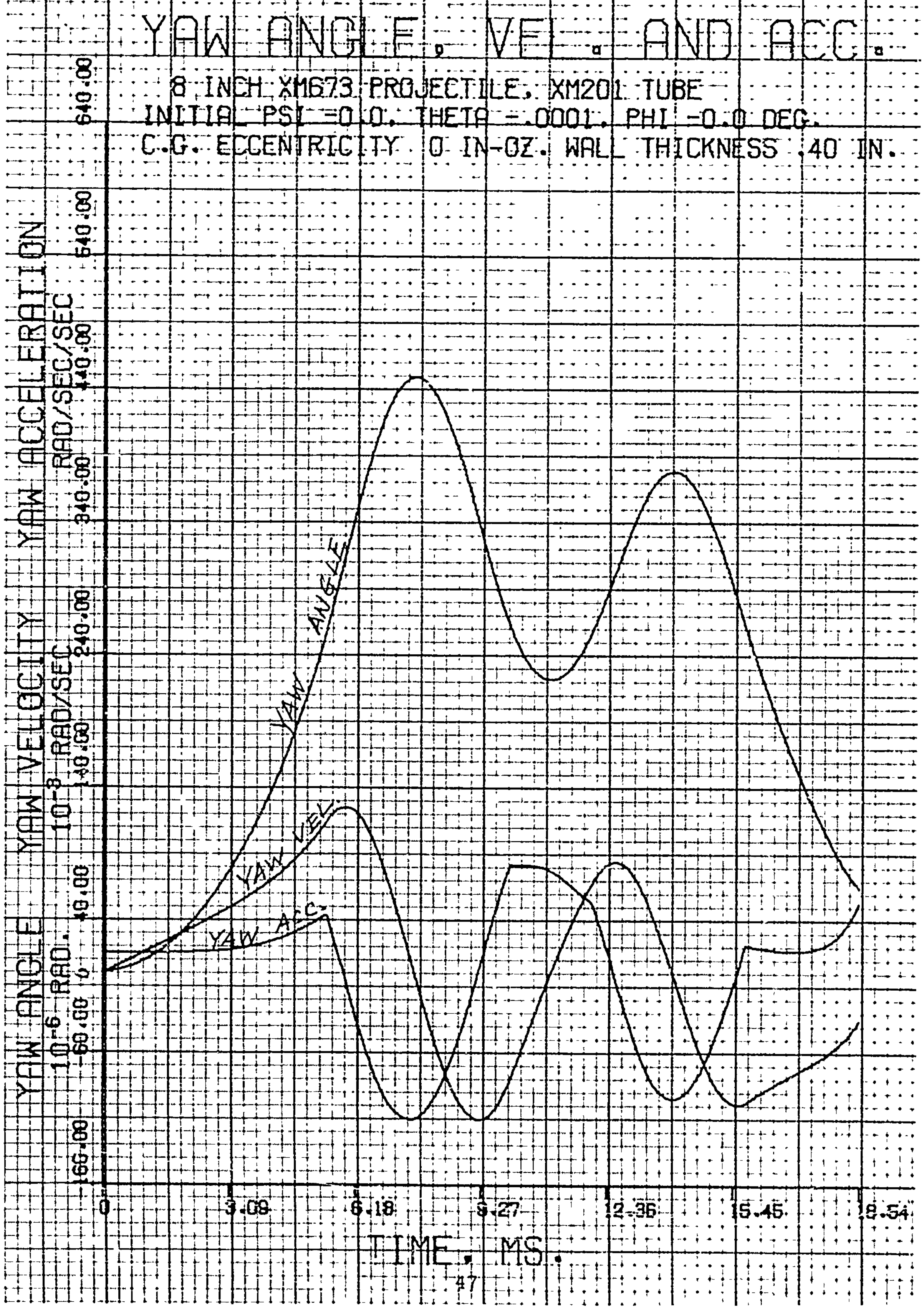
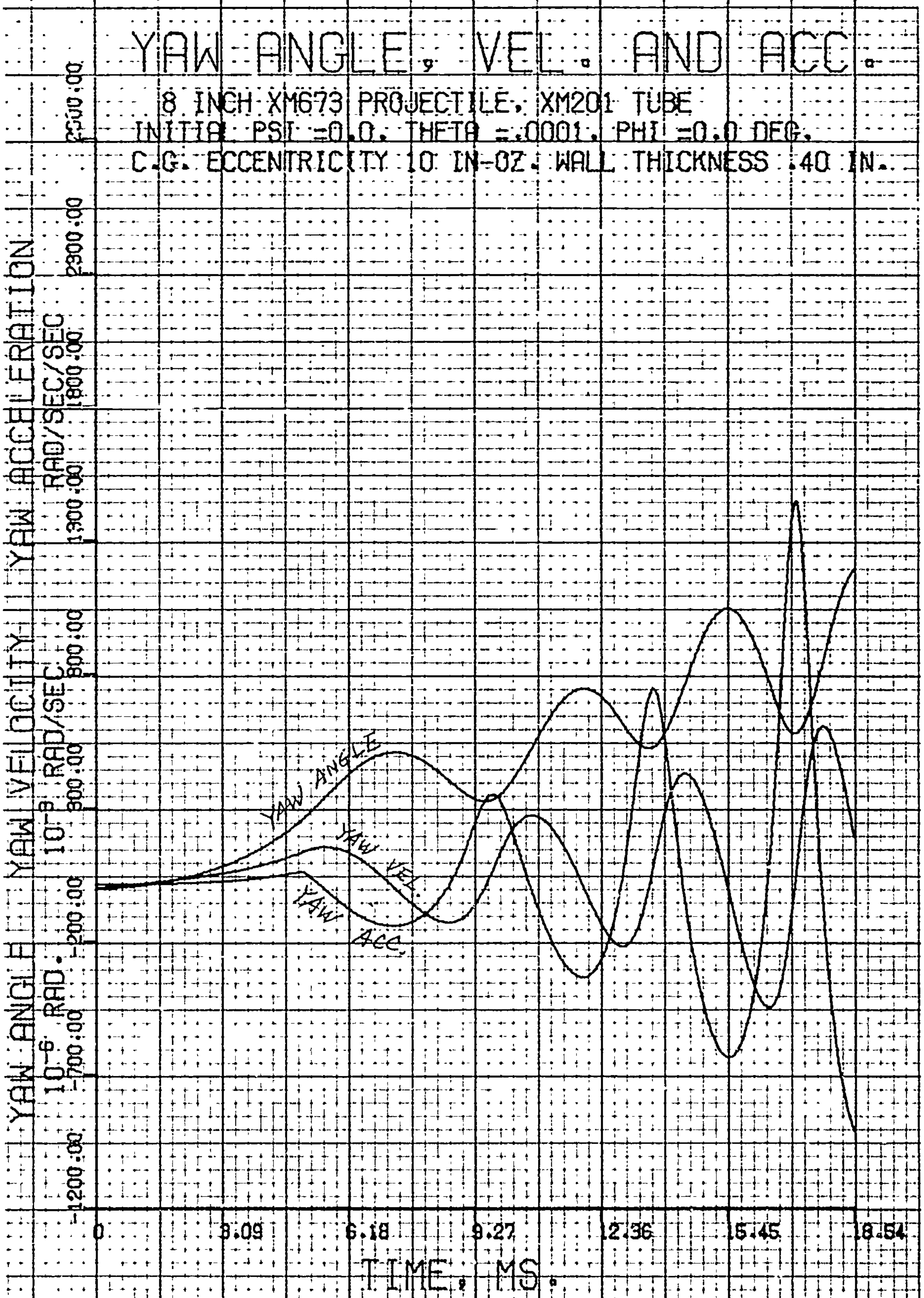

CONTACT POINT AND DEFLECTION
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .40 IN.
C.G. TO DRIVING BAND DISTANCE REDCUED TO ½ ORIGINAL VALUE
CONTACT ANGLE,DEG., DEFLECTION,10^-4 IN.
900.00
775.00
650.00
525.00
400.00
275.00
150.00
25.00
-100.00
CONTACT POINT ON GUN TUBE
DEFLECTION AT BOURRELET
CONTACT POINT
0
45.67
91.33
137.00
182.67
228.33
274.00
TRAVEL, IN.

FIGURE 12a



YAW ANGLE, VEL. AND ACC.
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ. WALL THICKNESS .40 IN.
YAW ANGLE YAW VELOCITY YAW ACCELERATION
10-6 RAD. 10-3 RAD/SEC RAD/SEC/SEC
-160.00
-60.00
0
40.00
140.00
240.00
340.00
440.00
540.00
640.00
YAW ANGLE
YAW VEL.
YAW ACC.
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.

FIGURE 12b



YAW ANGLE, VEL. AND ACC.
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ. WALL THICKNESS .40 IN.
YAW ANGLE YAW VELOCITY YAW ACCELERATION
10-6 RAD. 10-3 RAD/SEC RAD/SEC/SEC
-1200.00
-700.00
-200.00
300.00
800.00
1300.00
1800.00
2300.00
2800.00
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.
YAW ANGLE
YAW VEL.
YAW ACC.

FIGURE 12c

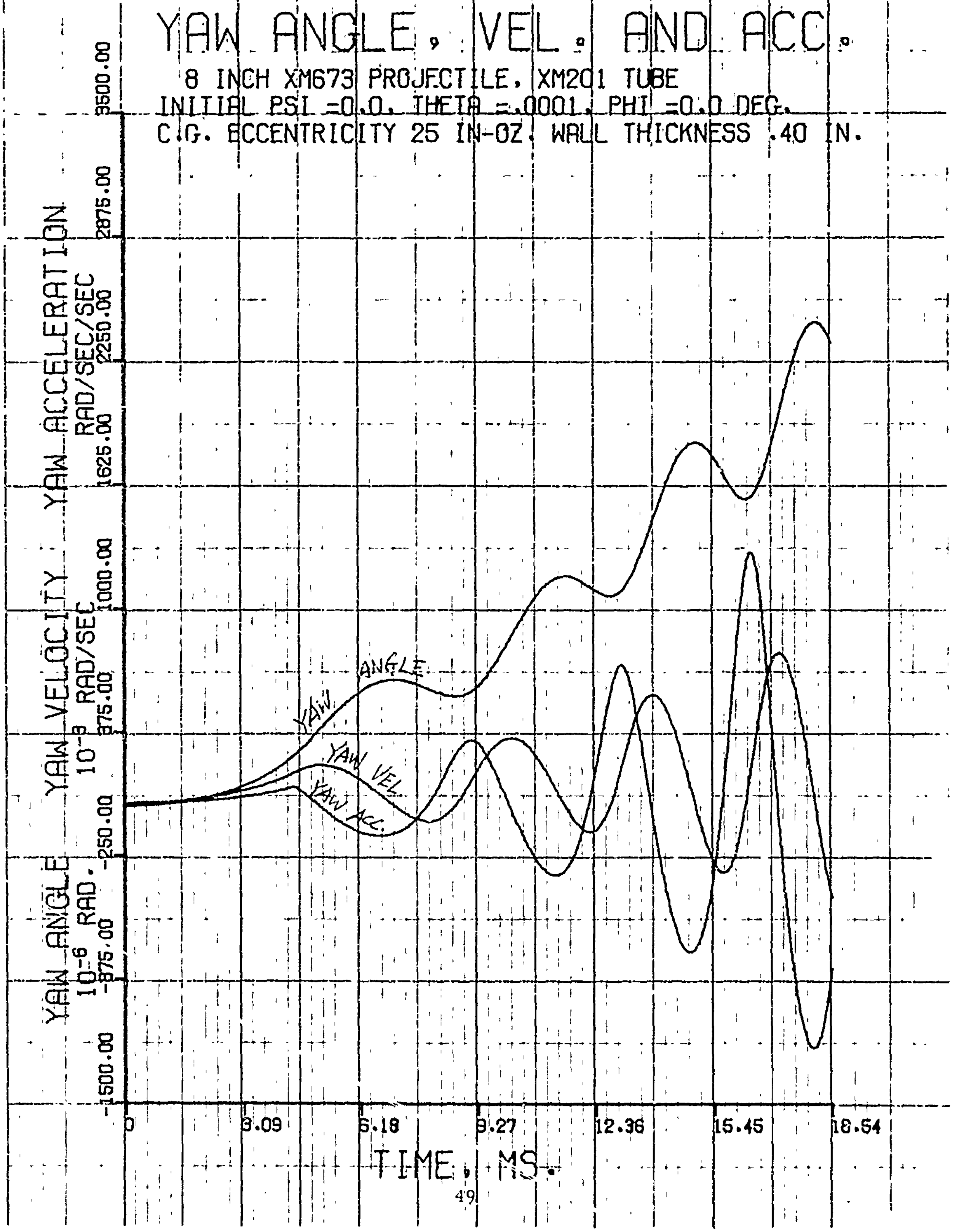

YAW ANGLE, VEL. AND ACC.
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ, WALL THICKNESS .40 IN.
YAW ANGLE YAW VELOCITY YAW ACCELERATION
10-6 RAD. 10-3 RAD/SEC RAD/SEC/SEC
3500.00
2875.00
2250.00
1625.00
1000.00
375.00
-250.00
-875.00
-1500.00
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.
YAW ANGLE
YAW VEL
YAW ACC.

FIGURE 12d

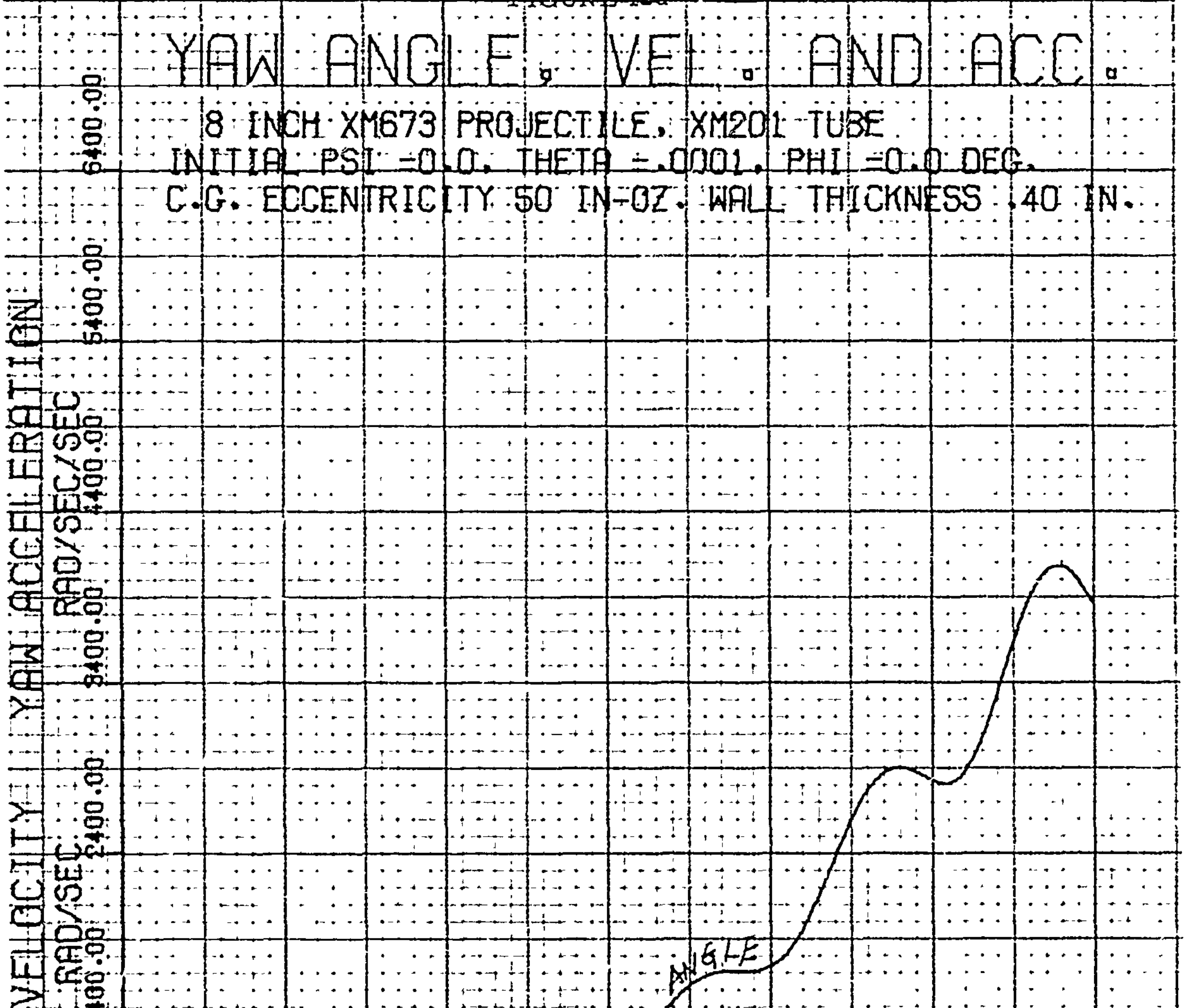

YAW ANGLE, VEL. AND ACC.
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ, WALL THICKNESS .40 IN.
YAW ANGLE YAW VELOCITY YAW ACCELERATION
10-6 RAD. 10-3 RAD/SEC RAD/SEC/SEC
-1600.00
-600.00
400.00
1400.00
2400.00
3400.00
4400.00
5400.00
6400.00
0
3.09
6.18
9.27
12.36
15.45
TIME, MS.
YAW ANGLE
YAW VEL.
YAW ACC.

FIGURE 13a

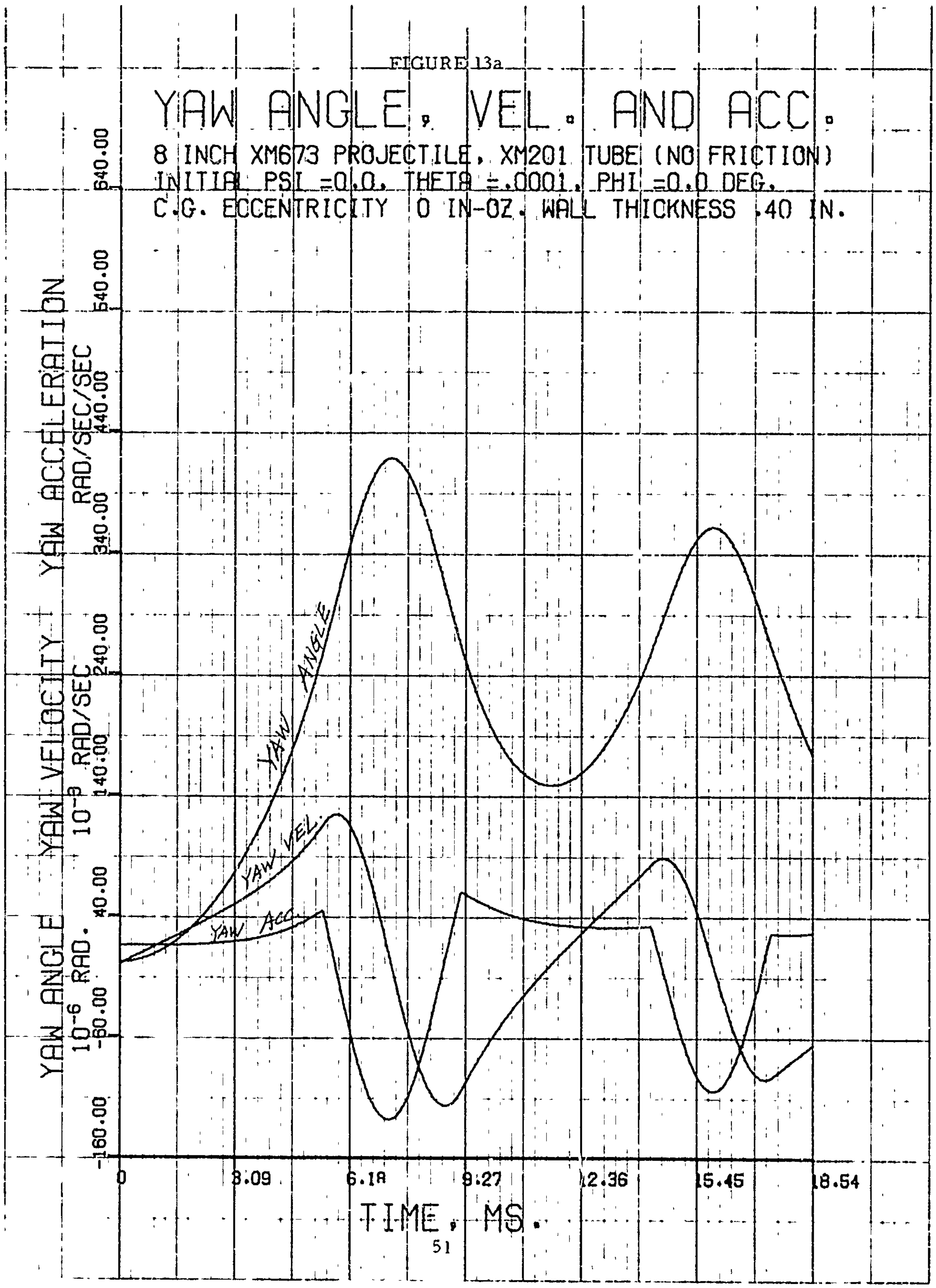

YAW ANGLE, VEL. AND ACC.
8 INCH XM673 PROJECTILE, XM201 TUBE (NO FRICTION)
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ. WALL THICKNESS .40 IN.
YAW ANGLE 10-6 RAD.
YAW VELOCITY 10-3 RAD/SEC
YAW ACCELERATION RAD/SEC/SEC
-160.00
-60.00
40.00
140.00
240.00
340.00
440.00
540.00
640.00
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.
YAW ANGLE
YAW VEL.
YAW ACC.

FIGURE 13b

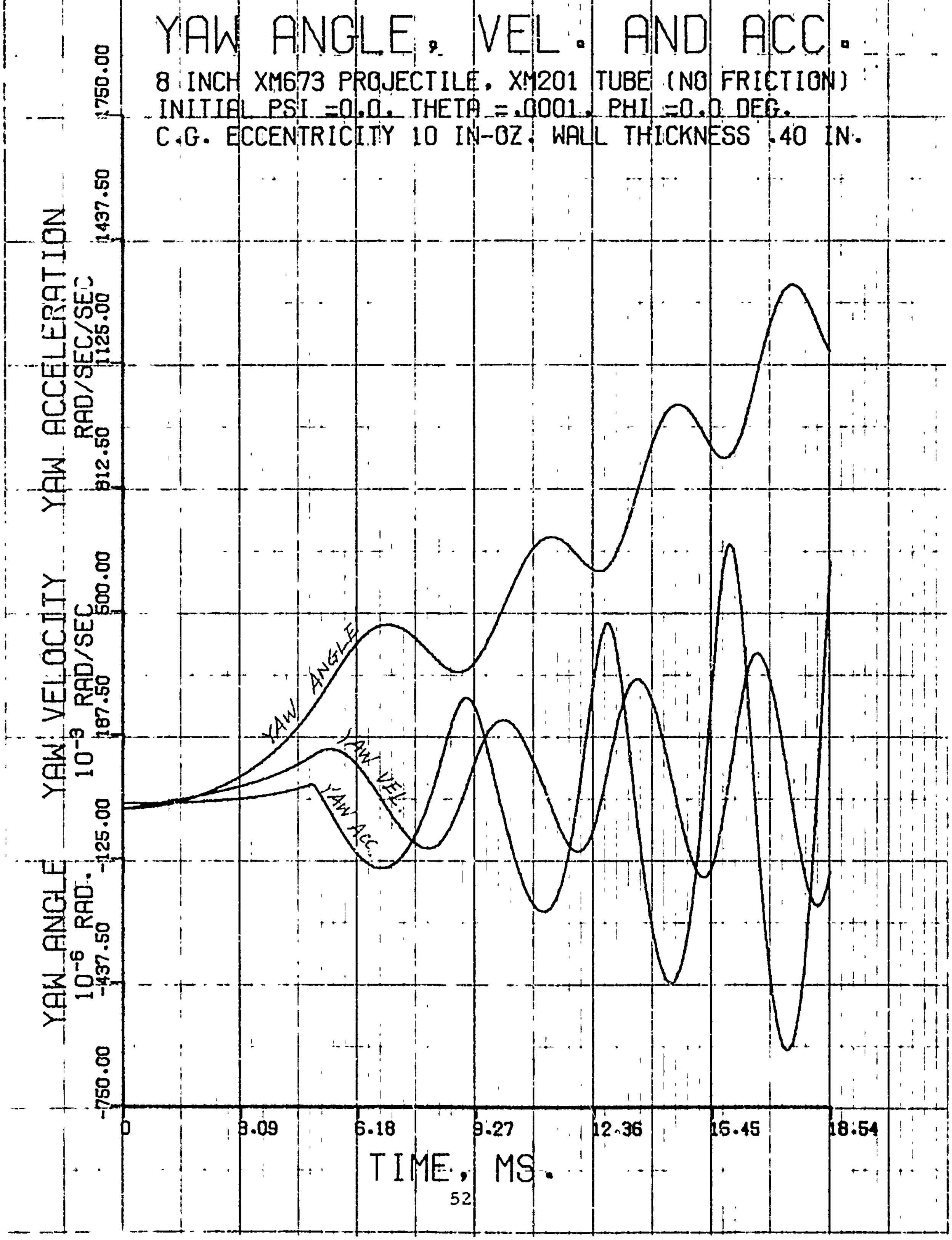

YAW ANGLE, VEL. AND ACC.
8 INCH XM673 PROJECTILE, XM201 TUBE (NO FRICTION)
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ, WALL THICKNESS .40 IN.
YAW ACCELERATION RAD/SEC/SEC
YAW VELOCITY 10-3 RAD/SEC
YAW ANGLE 10-6 RAD.
1750.00
1437.50
1125.00
812.50
500.00
187.50
-125.00
-437.50
-750.00
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.
YAW ANGLE
YAW VEL.
YAW ACC.

FIGURE 13c

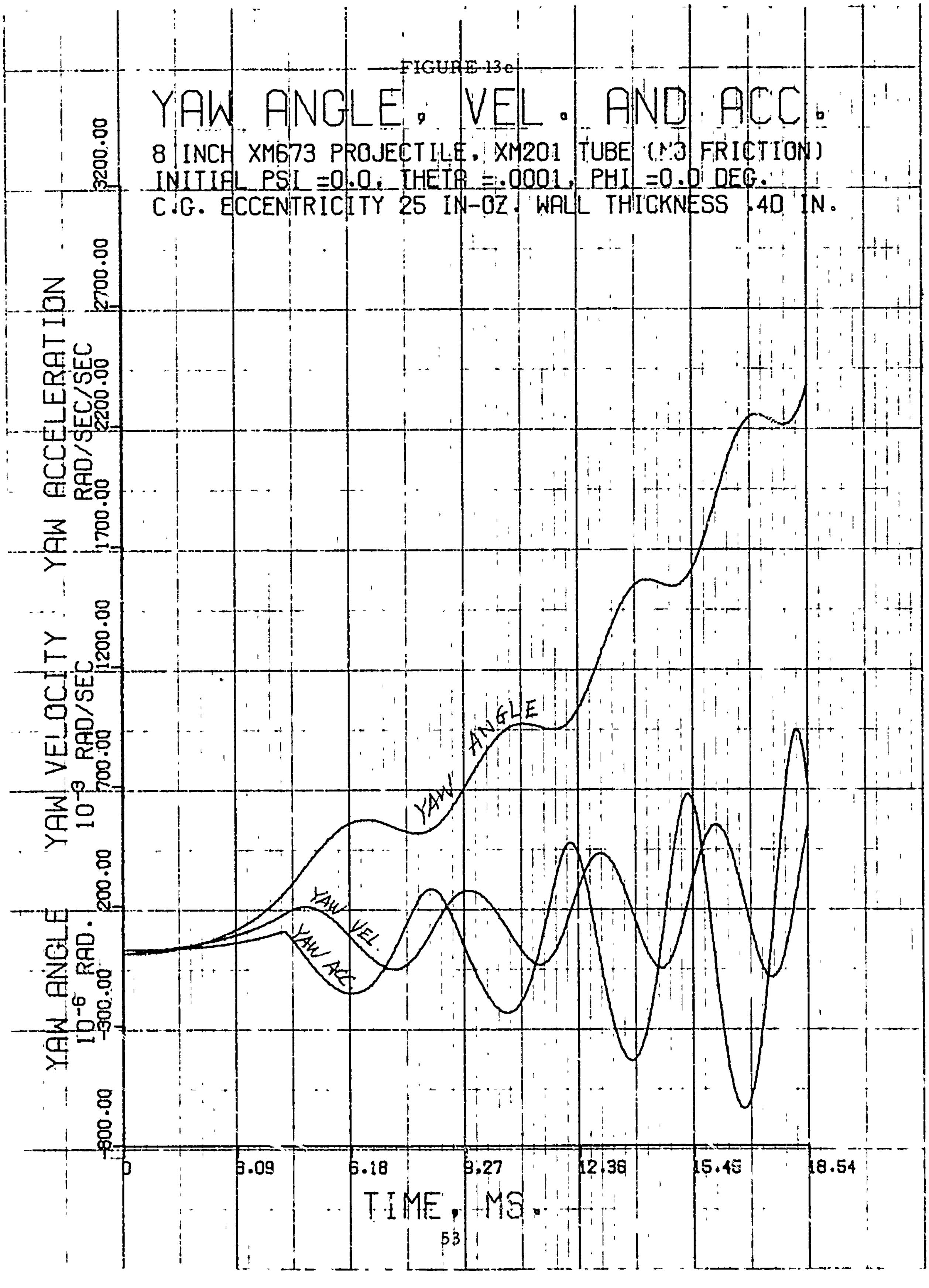

YAW ANGLE, VEL. AND ACC.
8 INCH XM673 PROJECTILE, XM201 TUBE (NO FRICTION)
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ, WALL THICKNESS .40 IN.
YAW ANGLE 10^{-6} RAD.
YAW VELOCITY 10^{-3} RAD/SEC
YAW ACCELERATION RAD/SEC/SEC
3200.00
2700.00
2200.00
1700.00
1200.00
700.00
200.00
-300.00
-800.00
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.
YAW ANGLE
YAW VEL.
YAW ACC.

FIGURE 13d

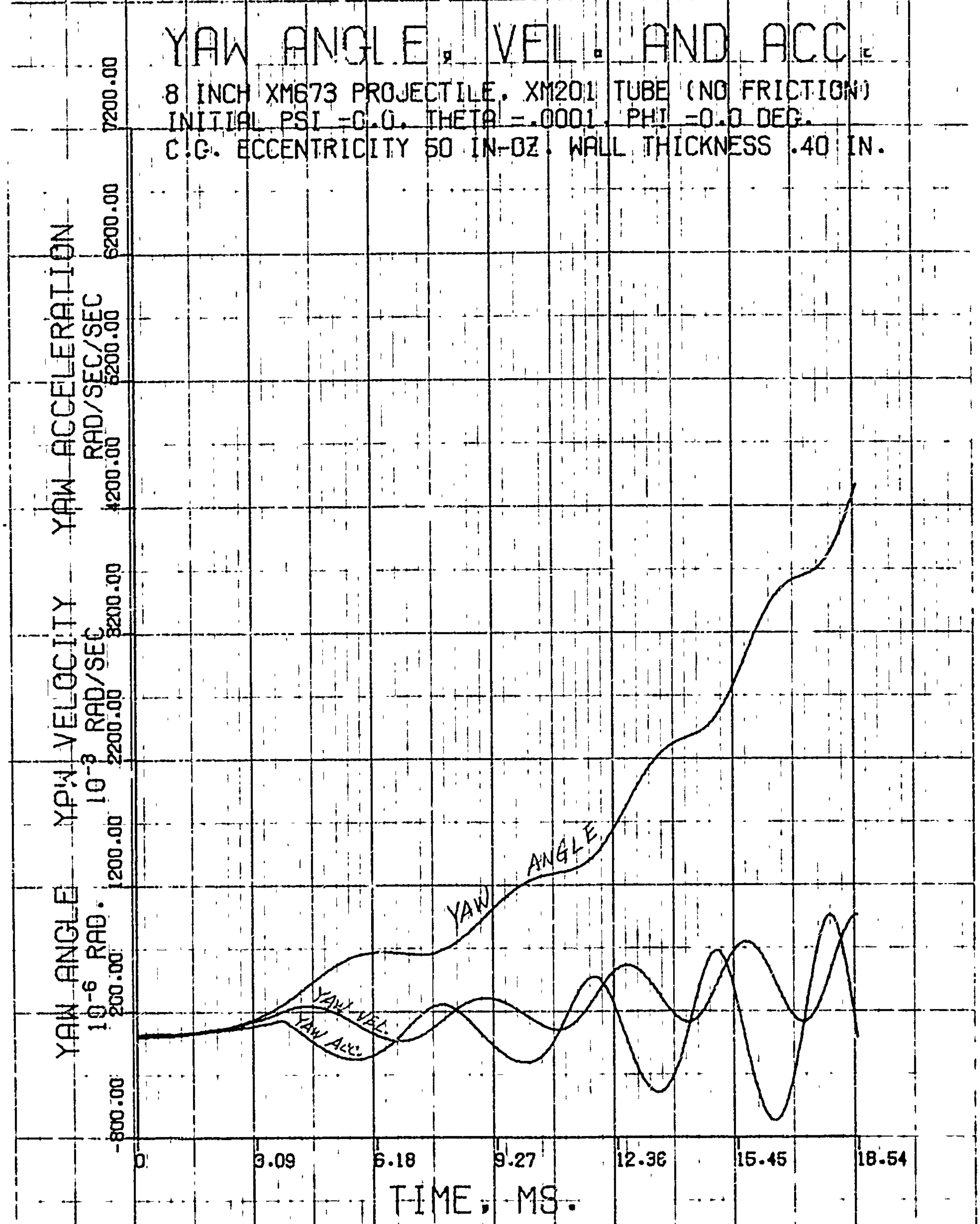

YAW ANGLE, VEL. AND ACC.
8 INCH XM673 PROJECTILE, XM201 TUBE (NO FRICTION)
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ, WALL THICKNESS .40 IN.
YAW ACCELERATION
RAD/SEC/SEC
YAW VELOCITY
10^{-3} RAD/SEC
YAW ANGLE
10^{-6} RAD.
7200.00
6200.00
5200.00
4200.00
3200.00
2200.00
1200.00
200.00
-800.00
0.
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.
YAW ANGLE
YAW VEL.
YAW ACC.

FIGURE 14a

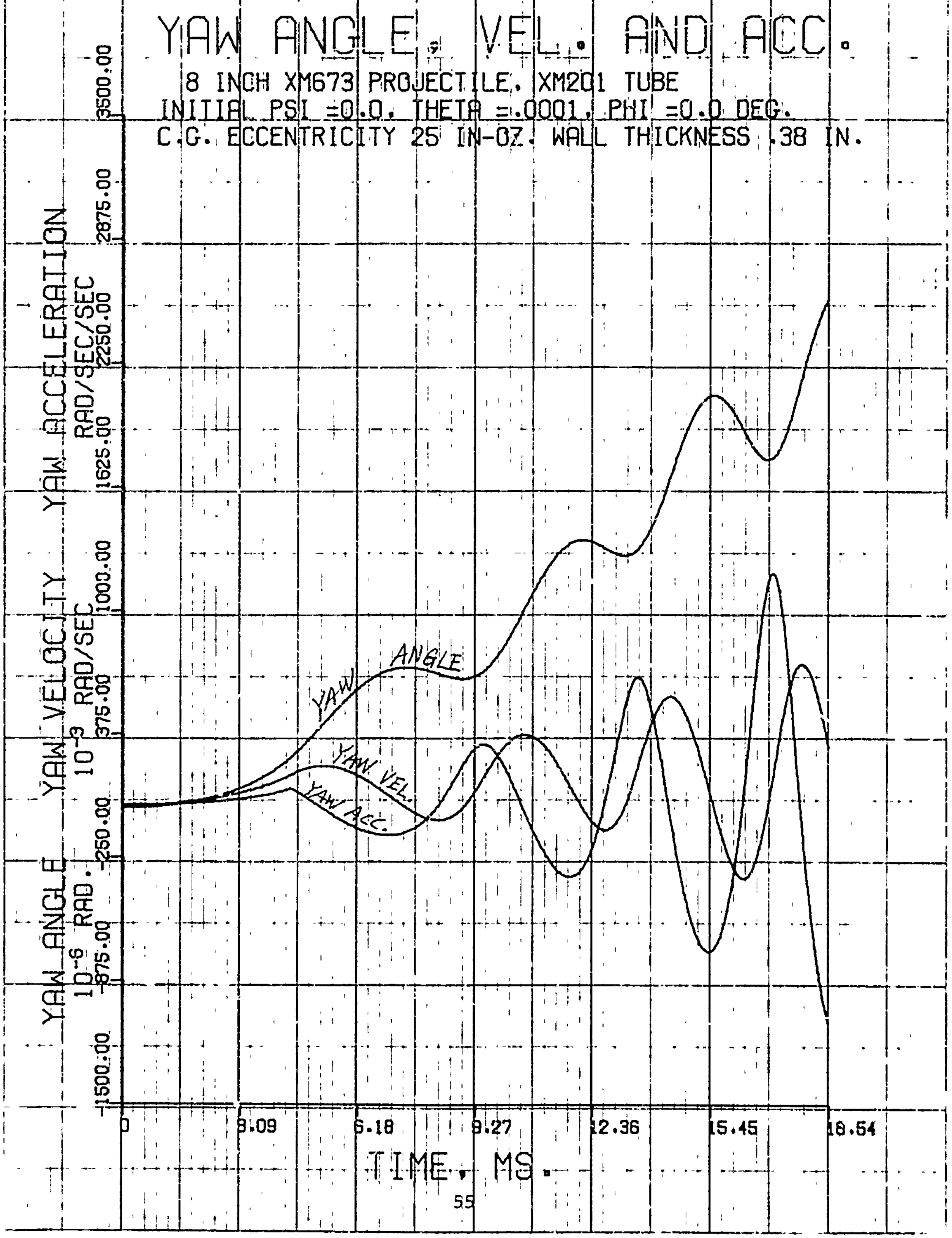

YAW ANGLE, VEL. AND ACC.
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .38 IN.
YAW ANGLE 10^-6 RAD.
YAW VELOCITY 10^-3 RAD/SEC
YAW ACCELERATION RAD/SEC/SEC
3500.00
2875.00
2250.00
1625.00
1000.00
375.00
-250.00
-875.00
-1500.00
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.
YAW ANGLE
YAW VEL.
YAW ACC.

FIGURE 14b

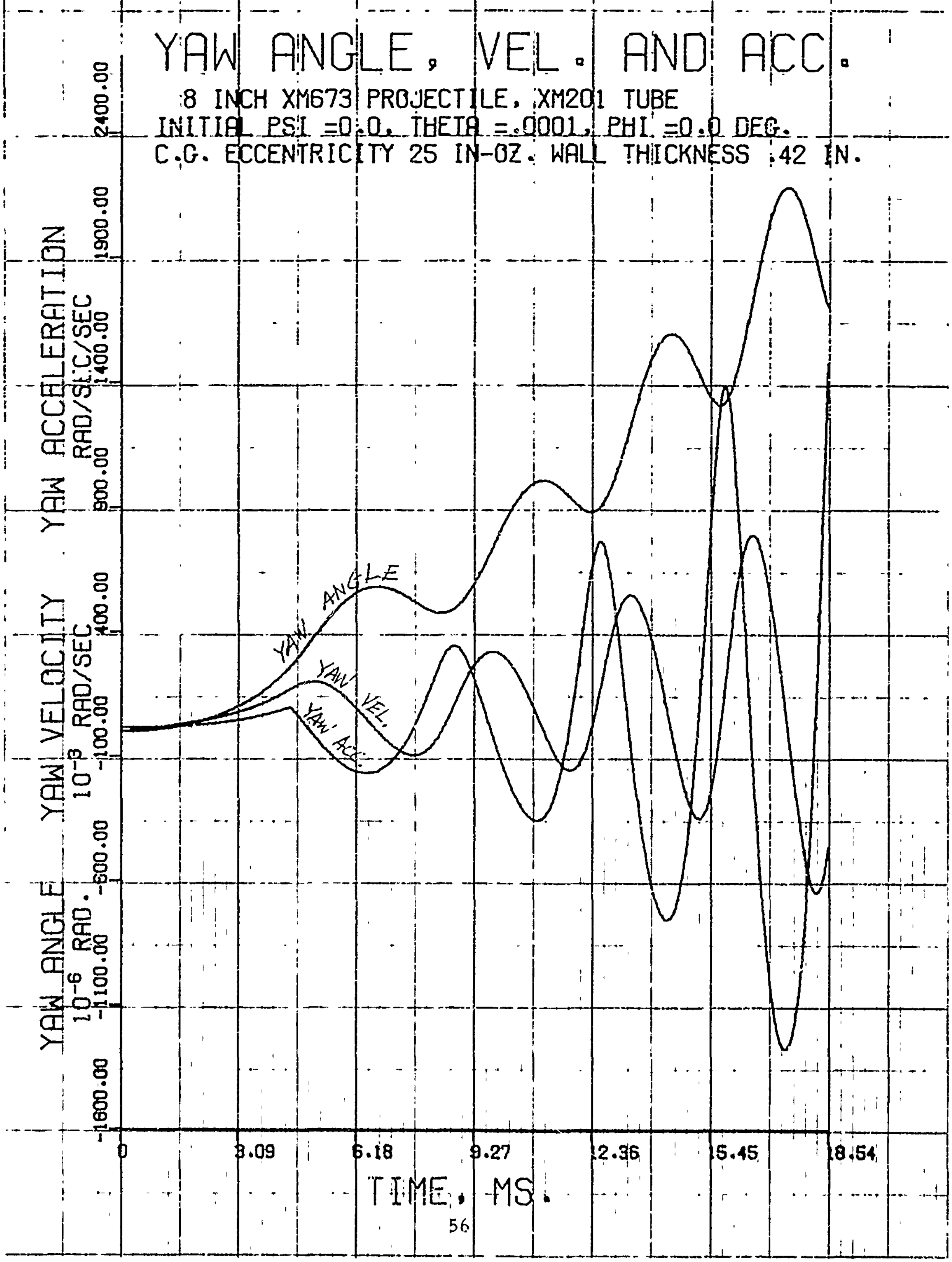
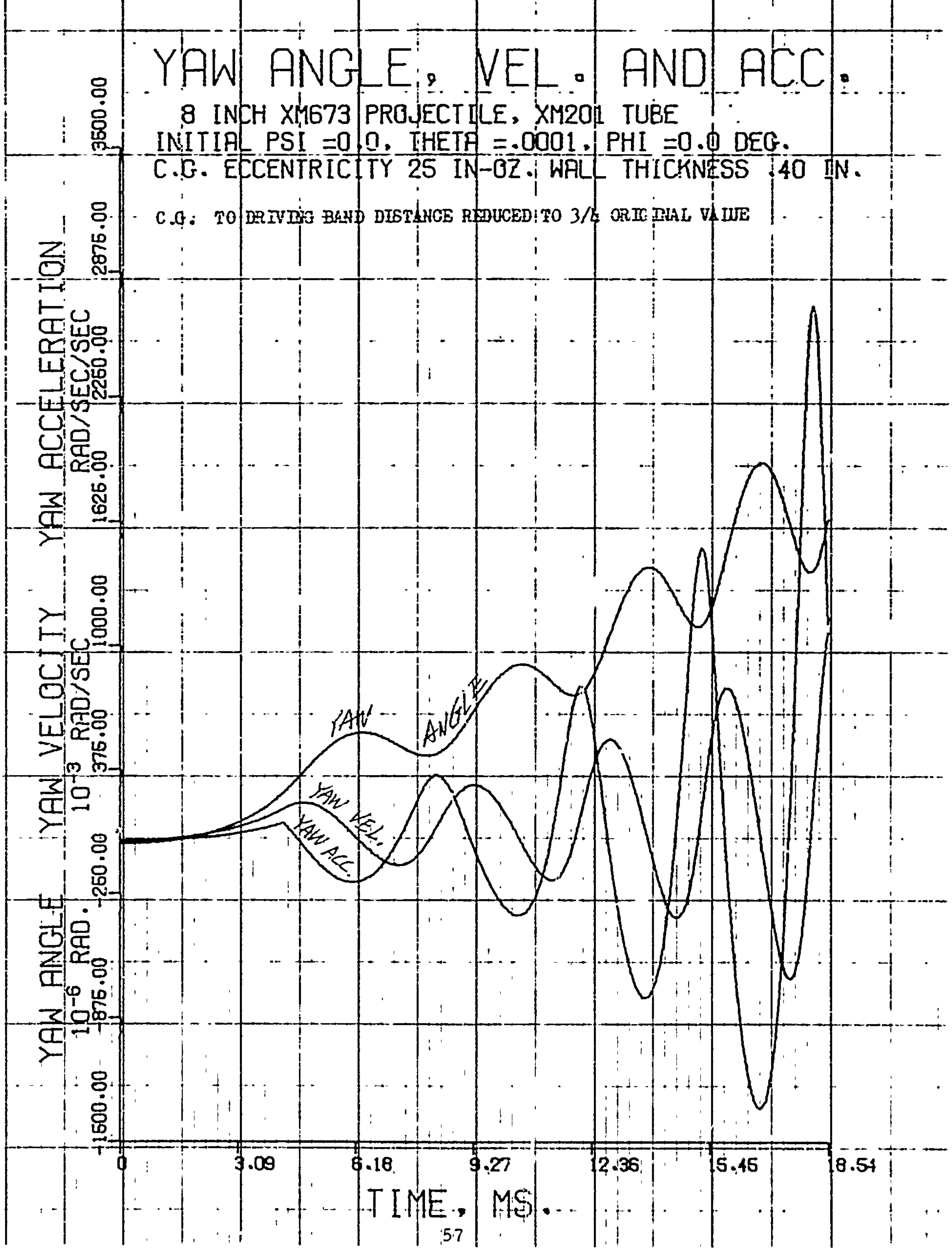

YAW ANGLE, VEL. AND ACC.
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .42 IN.
YAW ANGLE 10-6 RAD.
YAW VELOCITY 10-3 RAD/SEC
YAW ACCELERATION RAD/SEC/SEC
2400.00
1900.00
1400.00
900.00
400.00
-100.00
-600.00
-1100.00
-1600.00
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.
YAW ANGLE
YAW VEL.
YAW ACC.

FIGURE 15a



YAW ANGLE, VEL. AND ACC.
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .40 IN.
C.G. TO DRIVING BAND DISTANCE REDUCED TO 3/4 ORIGINAL VALUE
YAW ANGLE 10-6 RAD.
YAW VELOCITY 10-3 RAD/SEC
YAW ACCELERATION RAD/SEC/SEC
3500.00
2875.00
2250.00
1625.00
1000.00
375.00
-250.00
-875.00
-1500.00
YAW ANGLE
YAW VEL.
YAW ACC.
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.

FIGURE 15b

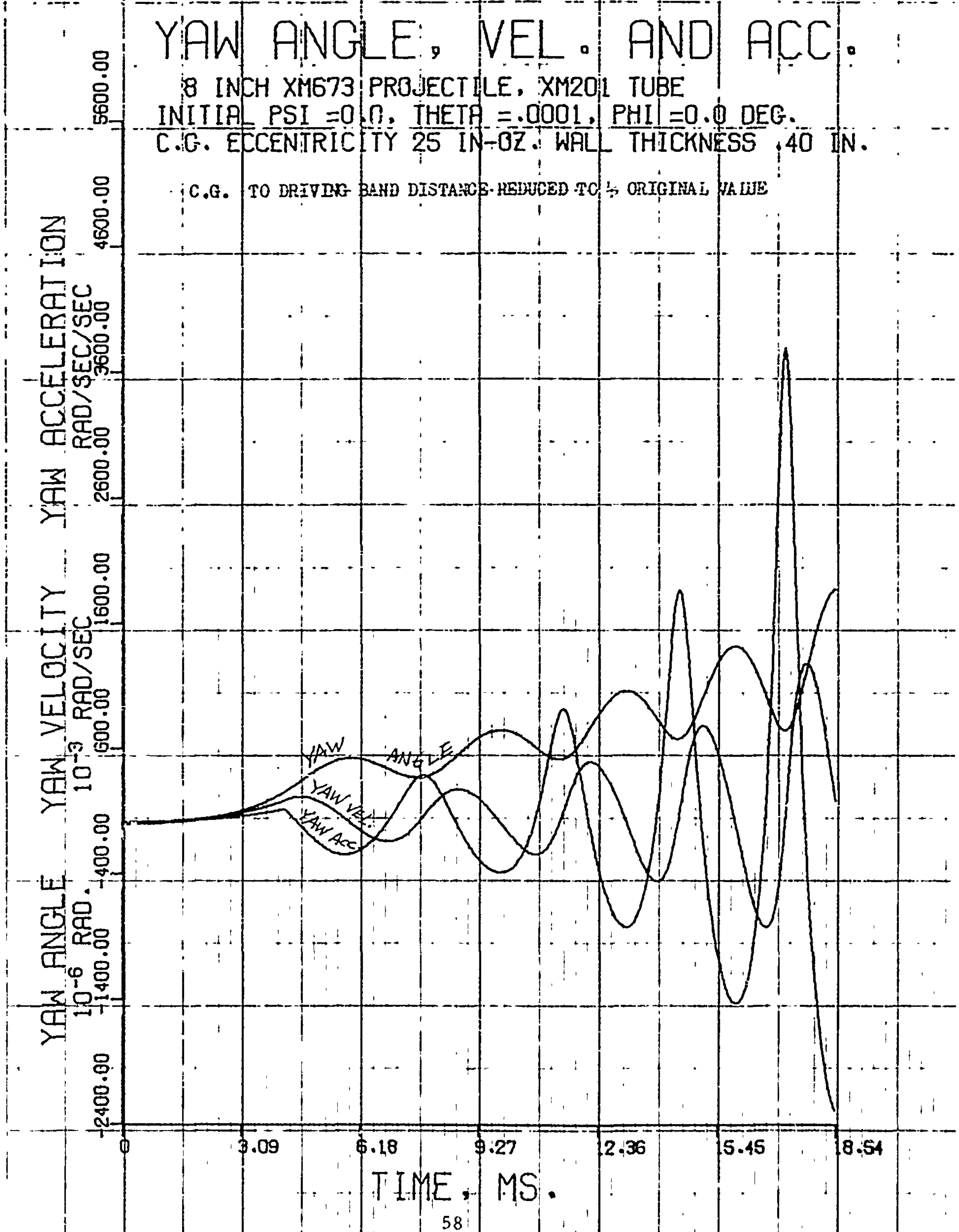

YAW ANGLE, VEL. AND ACC.
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .40 IN.
C.G. TO DRIVING BAND DISTANCE REDUCED TO ½ ORIGINAL VALUE
YAW ACCELERATION RAD/SEC/SEC
YAW VELOCITY 10^{-3} RAD/SEC
YAW ANGLE 10^{-6} RAD.
5600.00
4600.00
3600.00
2600.00
1600.00
600.00
-400.00
-1400.00
-2400.00
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.
YAW ANGLE
YAW VEL.
YAW ACC

FIGURE 16a

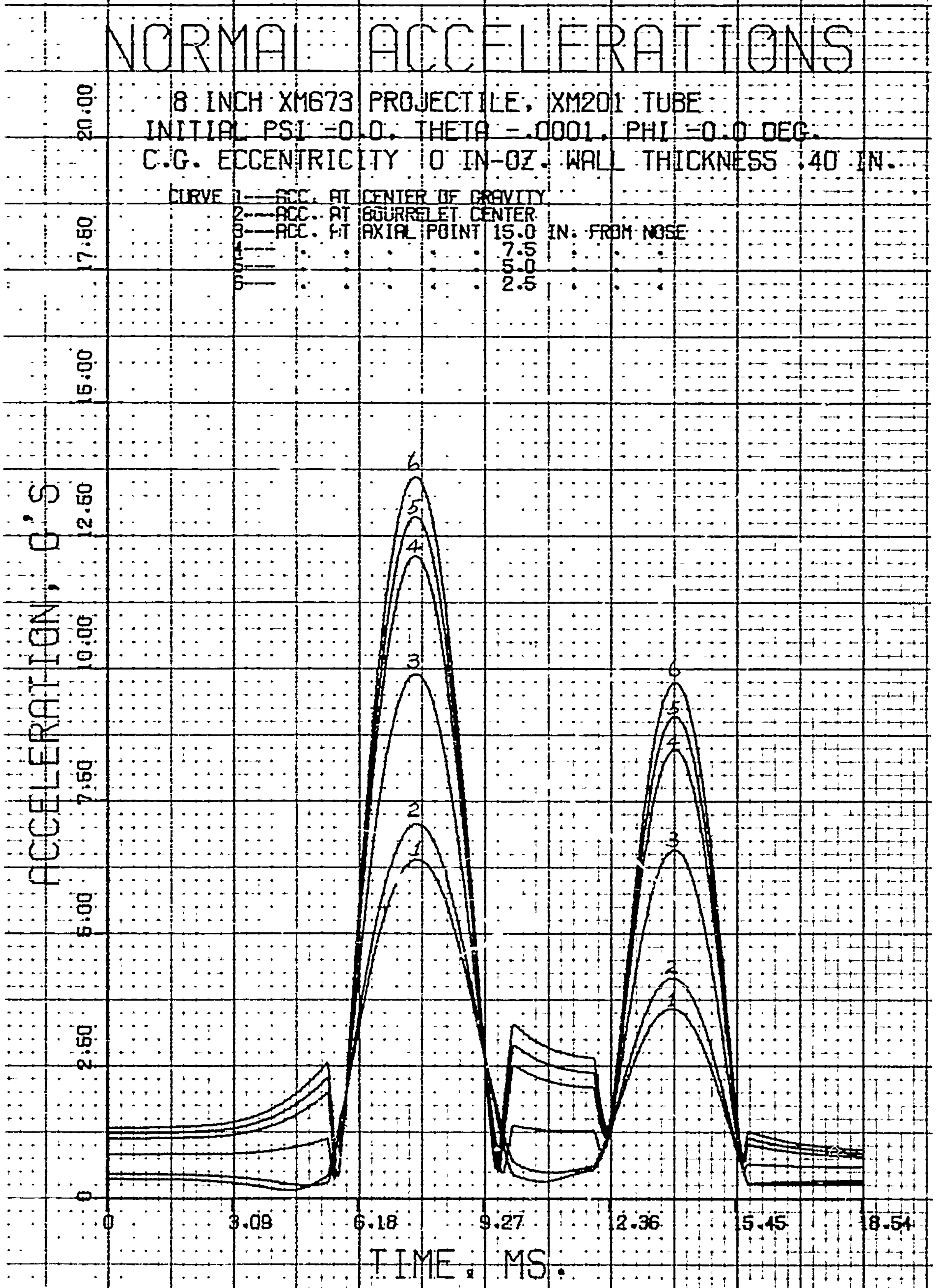

NORMAL ACCELERATIONS
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ. WALL THICKNESS .40 IN.
CURVE 1---ACC. AT CENTER OF GRAVITY
2---ACC. AT BOURRELET CENTER
3---ACC. AT AXIAL POINT 15.0 IN. FROM NOSE
4--- 7.5
5--- 5.0
6--- 2.5
ACCELERATION, G'S
20.00
17.50
15.00
12.50
10.00
7.50
5.00
2.50
0
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.
1
2
3
4
5
6

FIGURE 16b

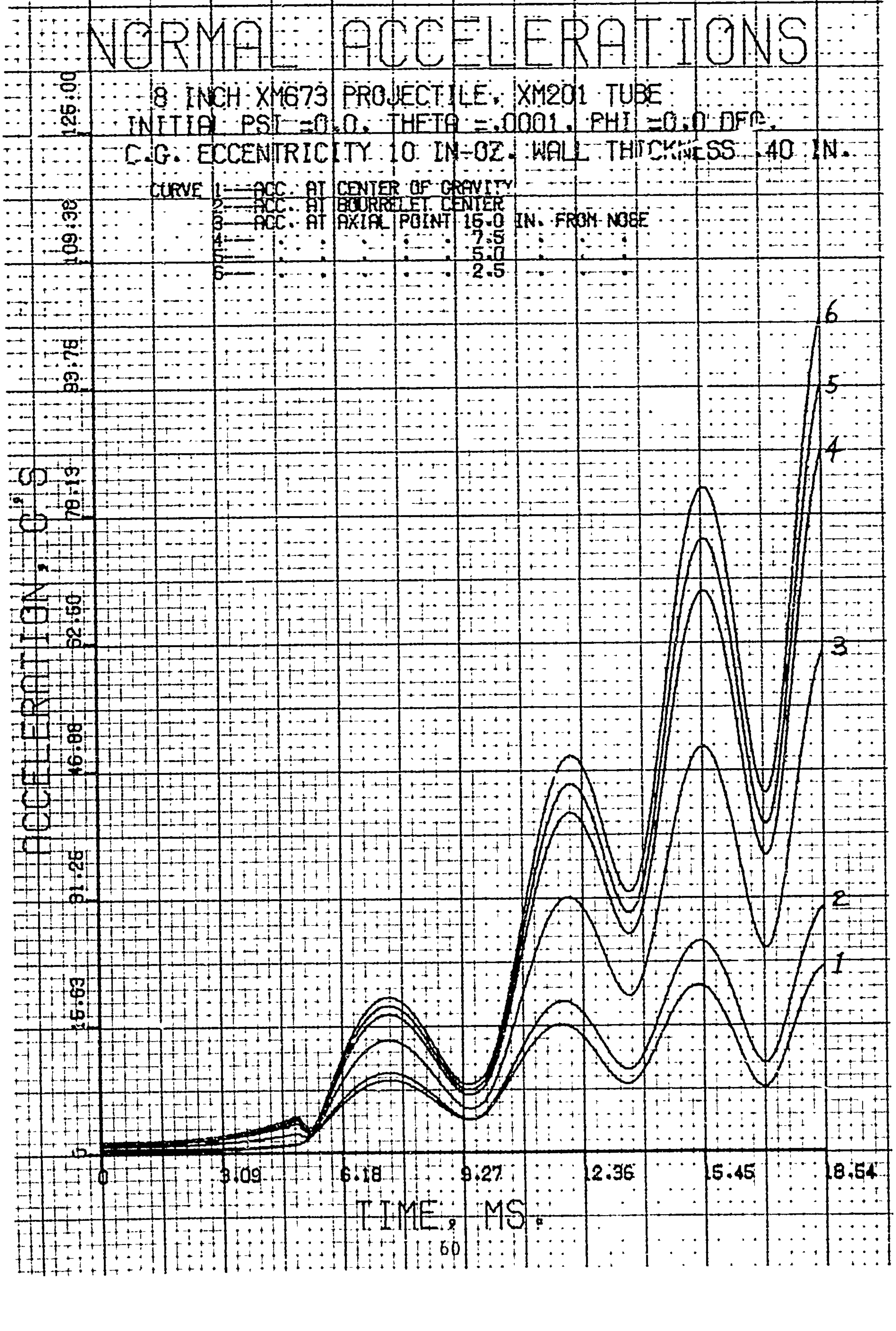

NORMAL ACCELERATIONS
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ, WALL THICKNESS .40 IN.
CURVE 1—ACC. AT CENTER OF GRAVITY
2—ACC. AT BOURRELET CENTER
3—ACC. AT AXIAL POINT 15.0 IN. FROM NOSE
4— 7.5
5— 5.0
6— 2.5
ACCELERATION, G'S
125.00
109.38
93.75
78.13
62.50
46.88
31.25
15.63
0
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.
1
2
3
4
5
6

FIGURE 16c

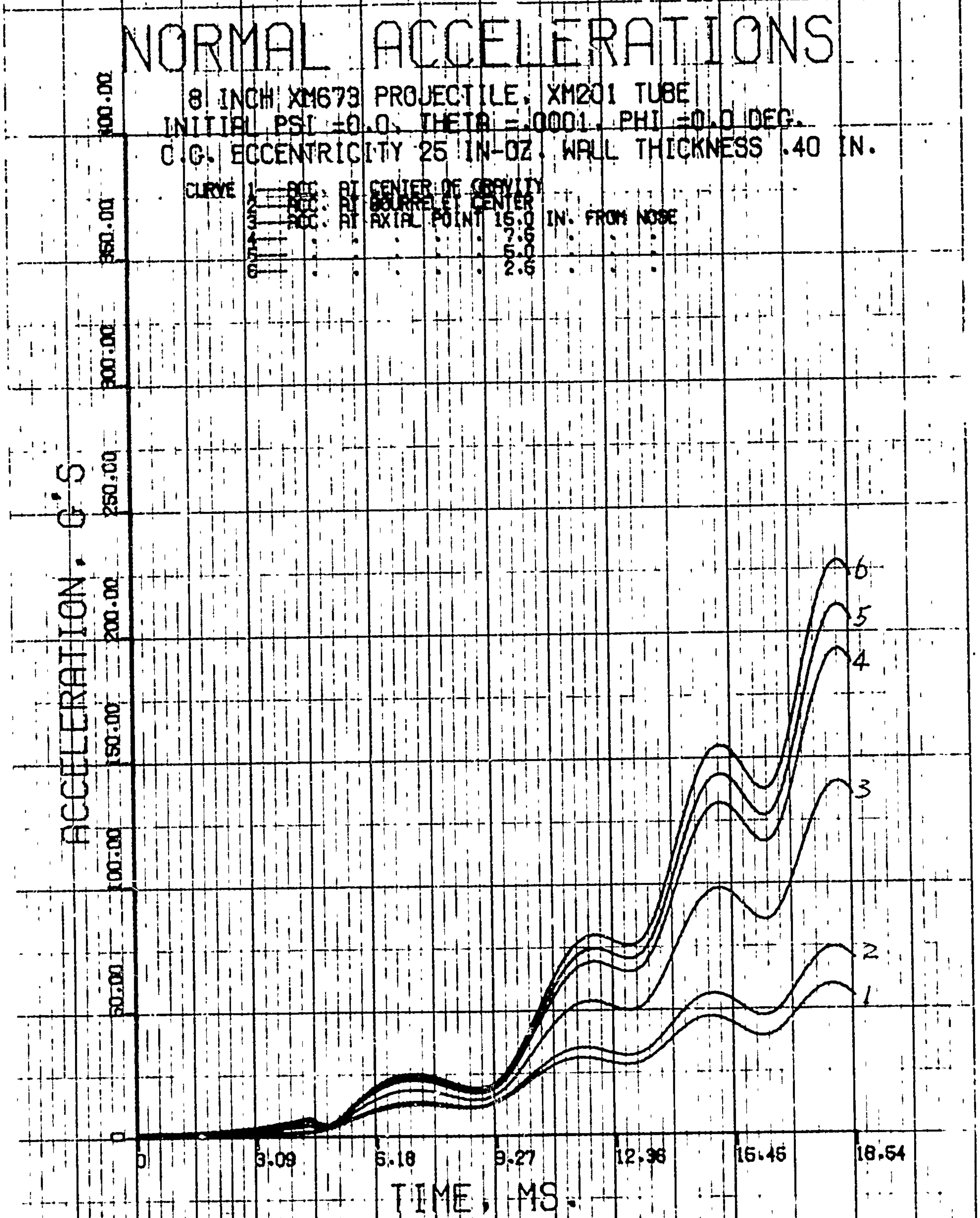

NORMAL ACCELERATIONS
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ, WALL THICKNESS .40 IN.
CURVE 1 — ACC. AT CENTER OF GRAVITY
2 — ACC. AT BOURRELET CENTER
3 — ACC. AT AXIAL POINT 15.0 IN. FROM NOSE
4 — 7.5
5 — 5.0
6 — 2.5
ACCELERATION, G'S
0
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.
1
2
3
4
5
6

FIGURE 16d

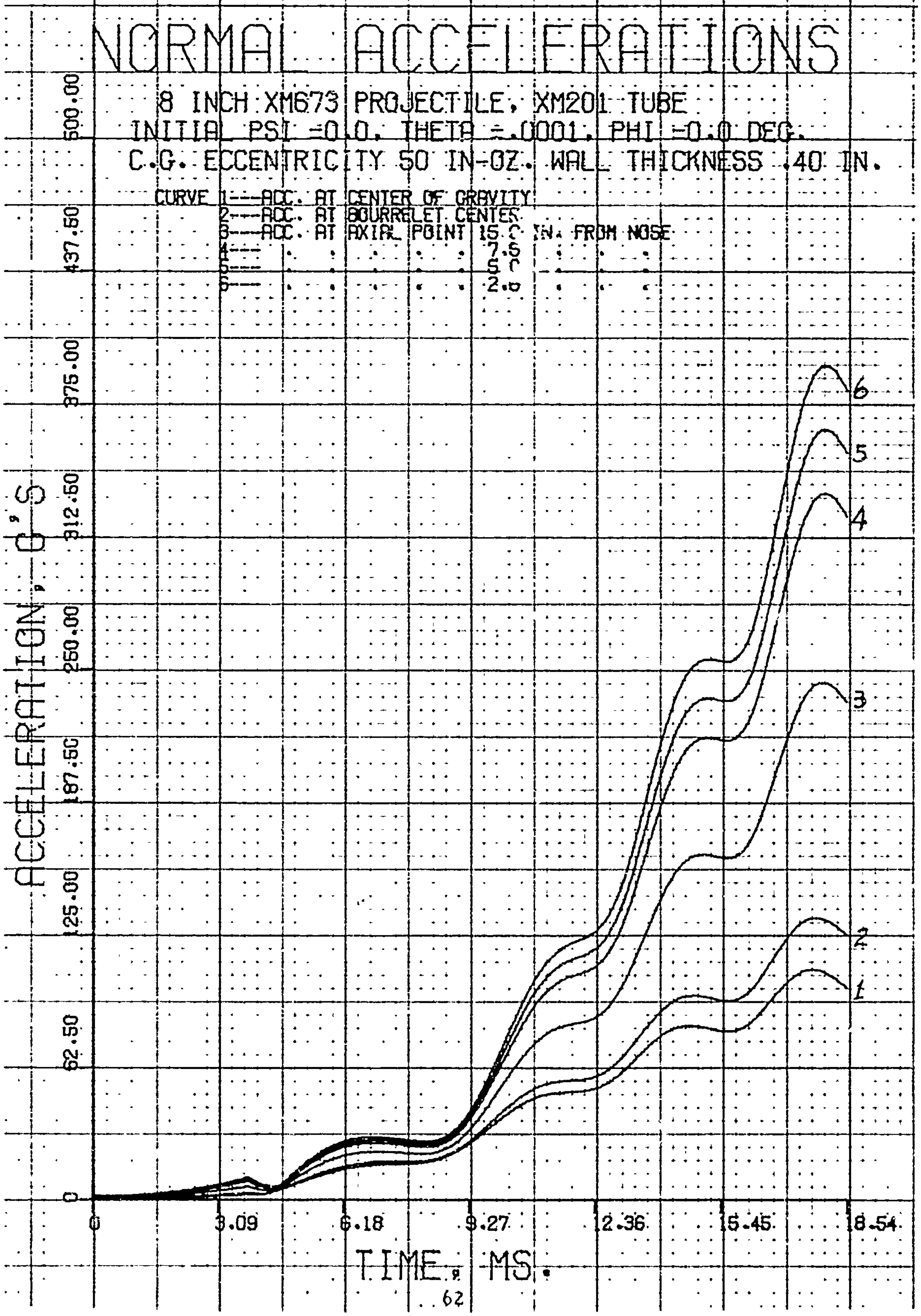

NORMAL ACCELERATIONS
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ. WALL THICKNESS .40 IN.
CURVE 1---ACC. AT CENTER OF GRAVITY
2---ACC. AT BOURRELET CENTER
3---ACC. AT AXIAL POINT 15.0 IN. FROM NOSE
4--- 7.5
5--- 5.0
6--- 2.5
ACCELERATION, G'S
500.00
437.50
375.00
312.50
250.00
187.50
125.00
62.50
0
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.
6
5
4
3
2
1

FIGURE 17a

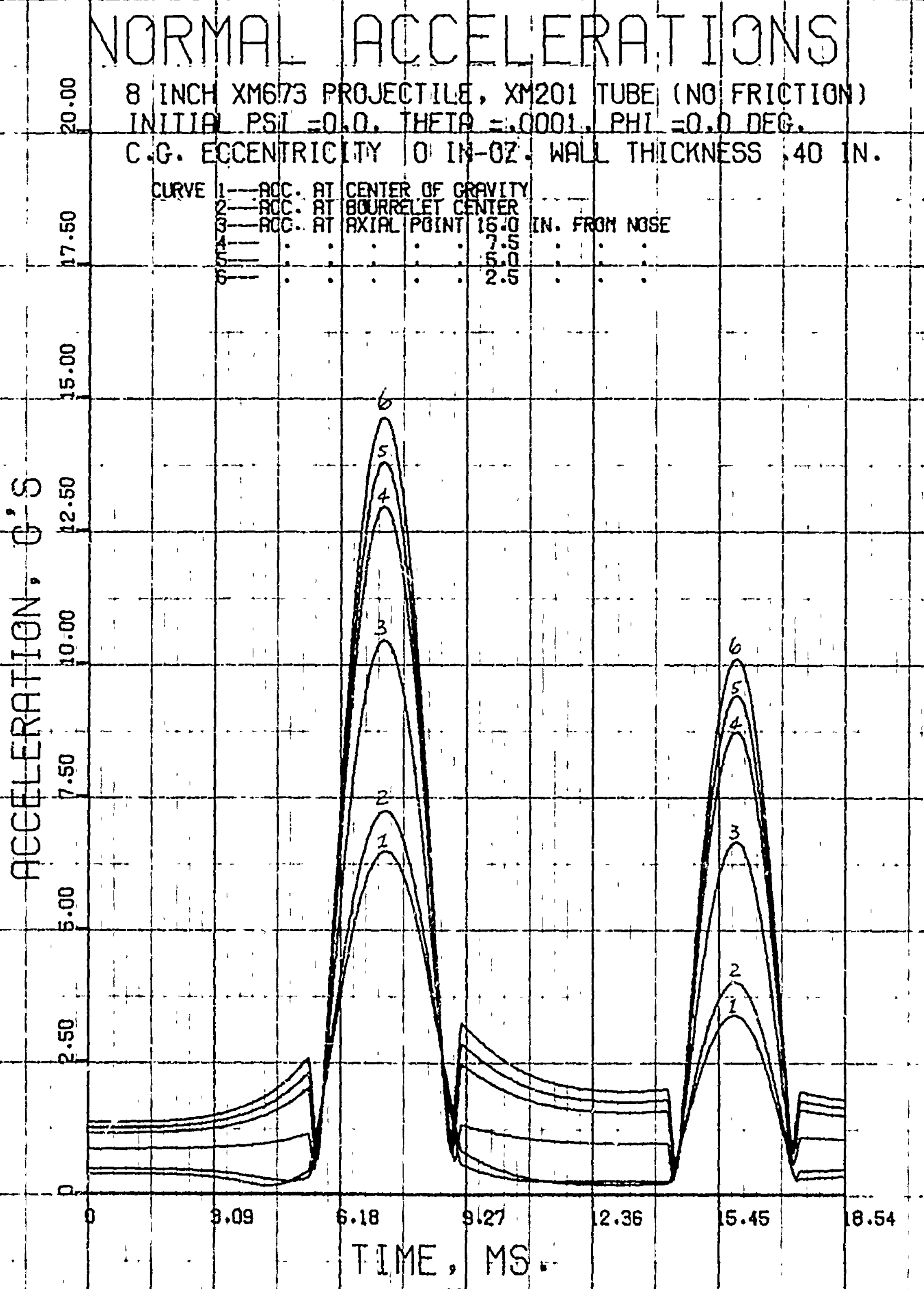

NORMAL ACCELERATIONS
8 INCH XM673 PROJECTILE, XM201 TUBE (NO FRICTION)
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ, WALL THICKNESS .40 IN.
CURVE 1---ACC. AT CENTER OF GRAVITY
2---ACC. AT BOURRELET CENTER
3---ACC. AT AXIAL POINT 16.0 IN. FROM NOSE
4--- " " " " 7.5 " " "
5--- " " " " 5.0 " " "
6--- " " " " 2.5 " " "
ACCELERATION, G'S
20.00
17.50
15.00
12.50
10.00
7.50
5.00
2.50
0
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.
6
5
4
3
2
1

FIGURE 17b

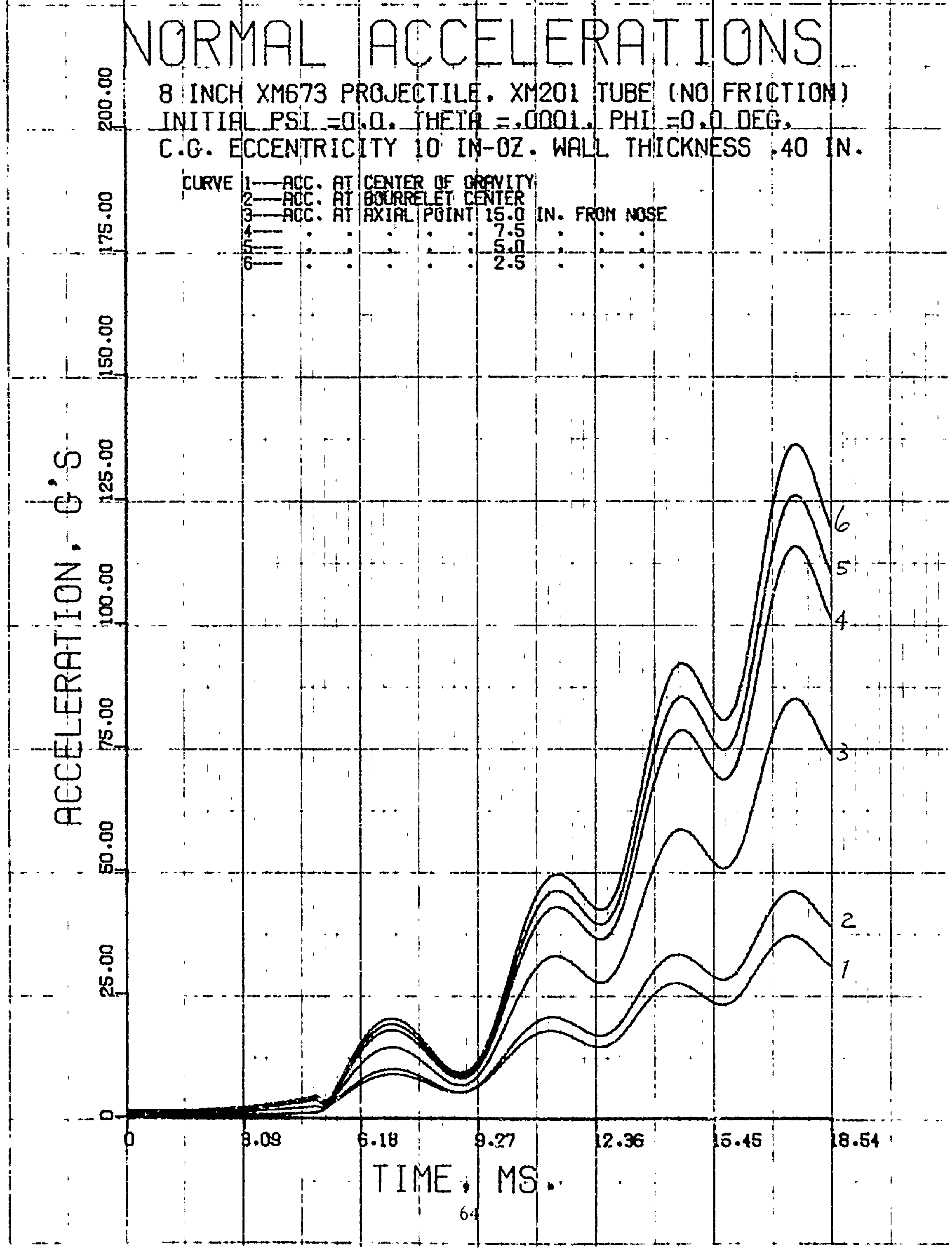

NORMAL ACCELERATIONS
8 INCH XM673 PROJECTILE, XM201 TUBE (NO FRICTION)
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ. WALL THICKNESS .40 IN.
CURVE 1---ACC. AT CENTER OF GRAVITY
2---ACC. AT BOURRELET CENTER
3---ACC. AT AXIAL POINT 15.0 IN. FROM NOSE
4--- . . . . . 7.5 . . .
5--- . . . . . 5.0 . . .
6--- . . . . . 2.5 . . .
ACCELERATION, G'S
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.
6
5
4
3
2
1

FIGURE 17c

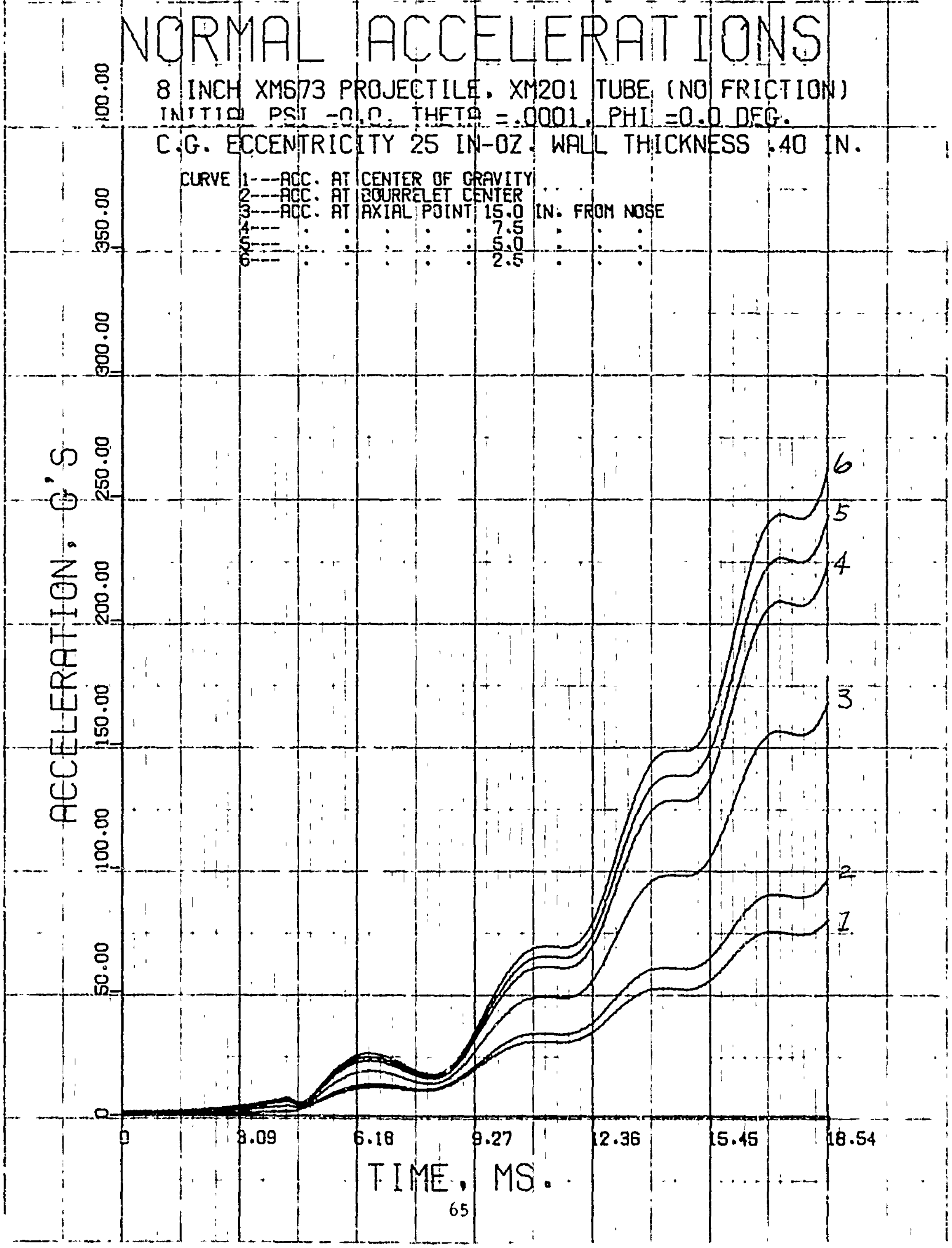

NORMAL ACCELERATIONS
8 INCH XM673 PROJECTILE, XM201 TUBE (NO FRICTION)
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .40 IN.
CURVE 1---ACC. AT CENTER OF GRAVITY
2---ACC. AT BOURRELET CENTER
3---ACC. AT AXIAL POINT 15.0 IN. FROM NOSE
4--- 7.5
5--- 5.0
6--- 2.5
ACCELERATION, G'S
TIME, MS.
0
3.09
6.18
9.27
12.36
15.45
18.54
0
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
1
2
3
4
5
6

FIGURE 17d

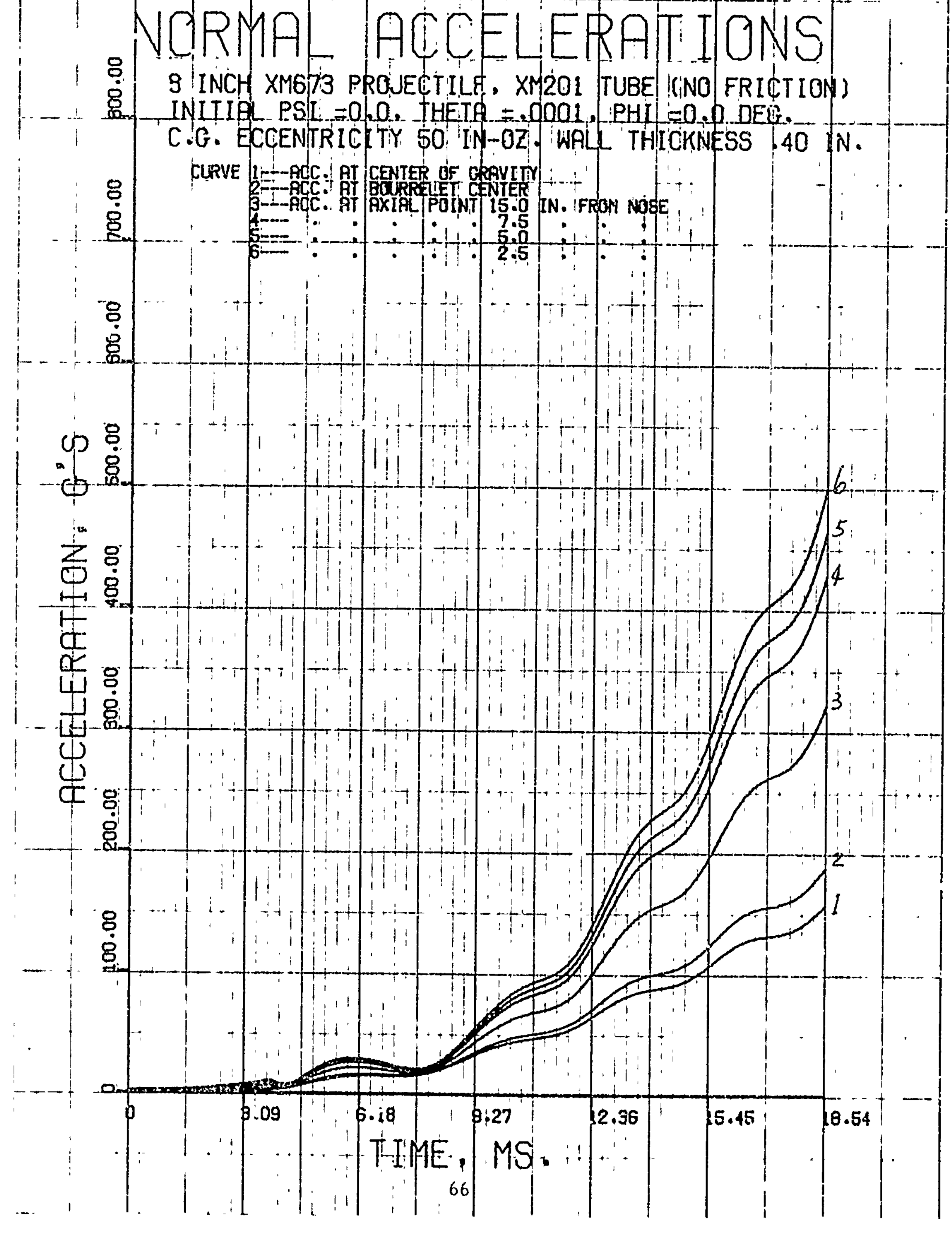

NORMAL ACCELERATIONS
8 INCH XM673 PROJECTILE, XM201 TUBE (NO FRICTION)
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ. WALL THICKNESS .40 IN.
CURVE 1---ACC. AT CENTER OF GRAVITY
2---ACC. AT BOURRELET CENTER
3---ACC. AT AXIAL POINT 15.0 IN. FROM NOSE
4--- " " " " 7.5 " " "
5--- " " " " 5.0 " " "
6--- " " " " 2.5 " " "
ACCELERATION, G'S
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0
TIME, MS.
0
3.09
6.18
9.27
12.36
15.45
18.54
6
5
4
3
2
1

FIGURE 18a

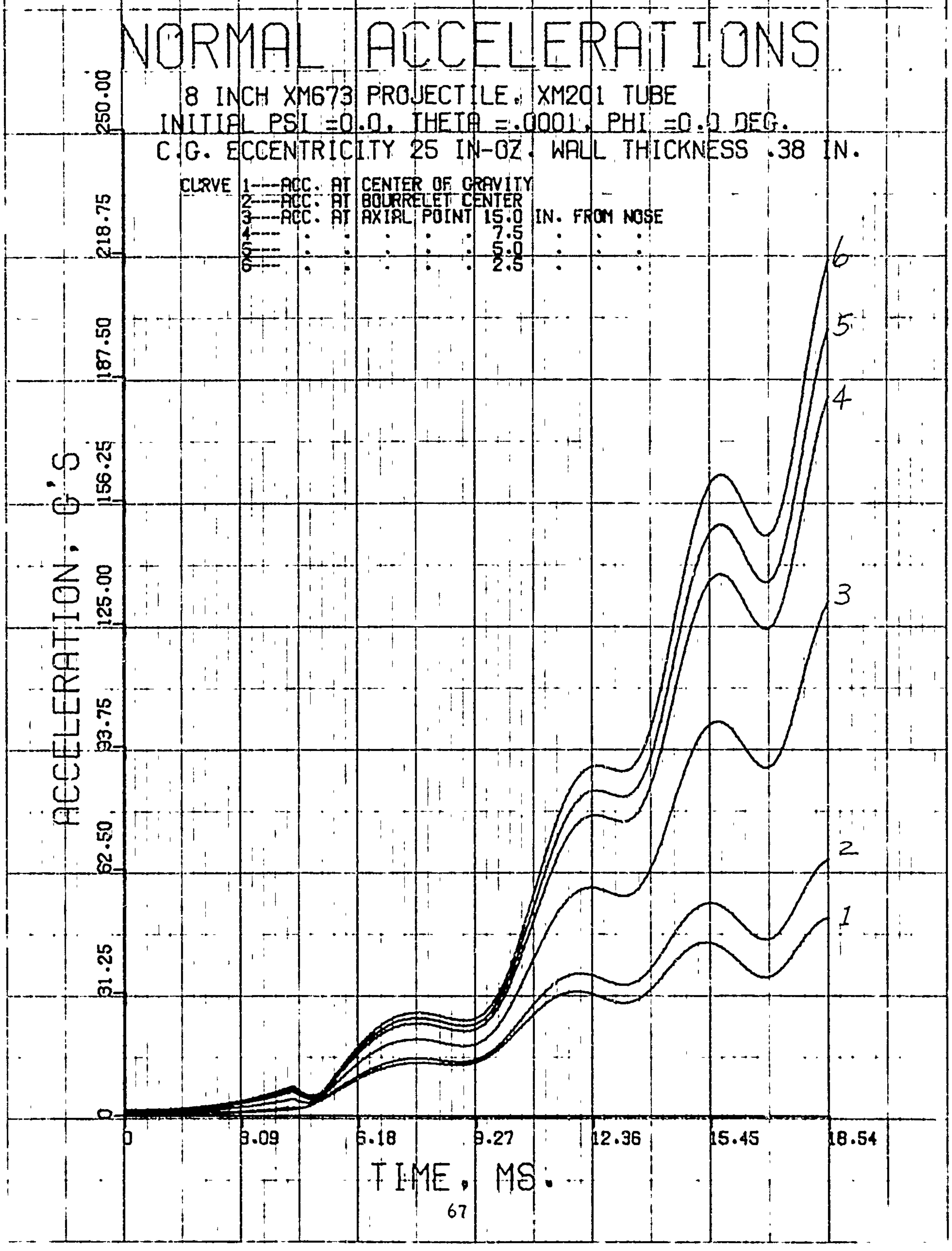

NORMAL ACCELERATIONS
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ, WALL THICKNESS .38 IN.
CURVE 1---ACC. AT CENTER OF GRAVITY
2---ACC. AT BOURRELET CENTER
3---ACC. AT AXIAL POINT 15.0 IN. FROM NOSE
4--- 7.5
5--- 5.0
6--- 2.5
ACCELERATION, G'S
250.00
218.75
187.50
156.25
125.00
93.75
62.50
31.25
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.
6
5
4
3
2
1

FIGURE 18b

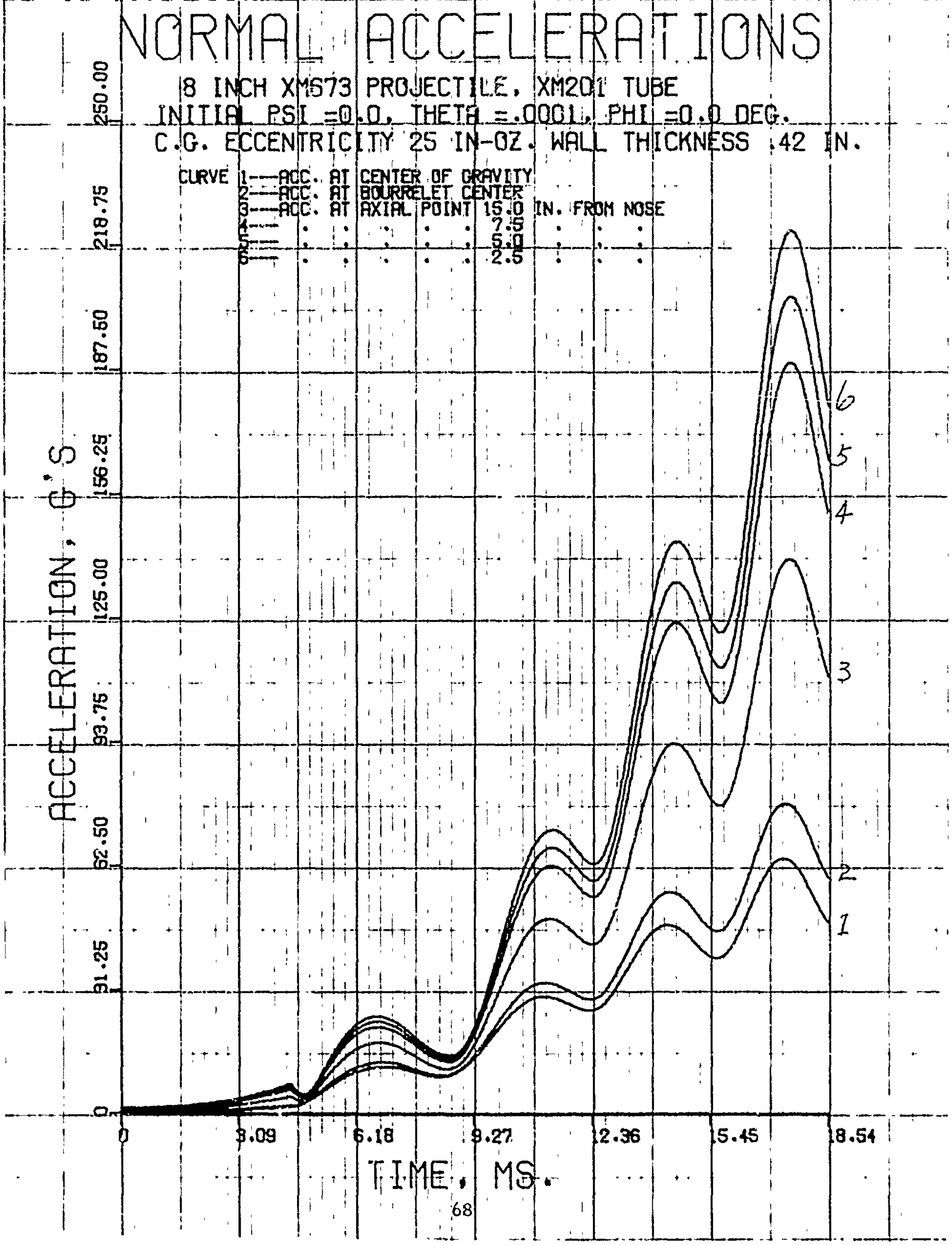

NORMAL ACCELERATIONS
8 INCH XM573 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .42 IN.
CURVE 1---ACC. AT CENTER OF GRAVITY
2---ACC. AT BOURRELET CENTER
3---ACC. AT AXIAL POINT 15.0 IN. FROM NOSE
4--- " " " " 7.5 " " "
5--- " " " " 5.0 " " "
6--- " " " " 2.5 " " "
ACCELERATION, G'S
250.00
218.75
187.50
156.25
125.00
93.75
62.50
31.25
0
TIME, MS.
0
3.09
6.18
9.27
12.36
15.45
18.54
6
5
4
3
2
1

FIGURE 19a

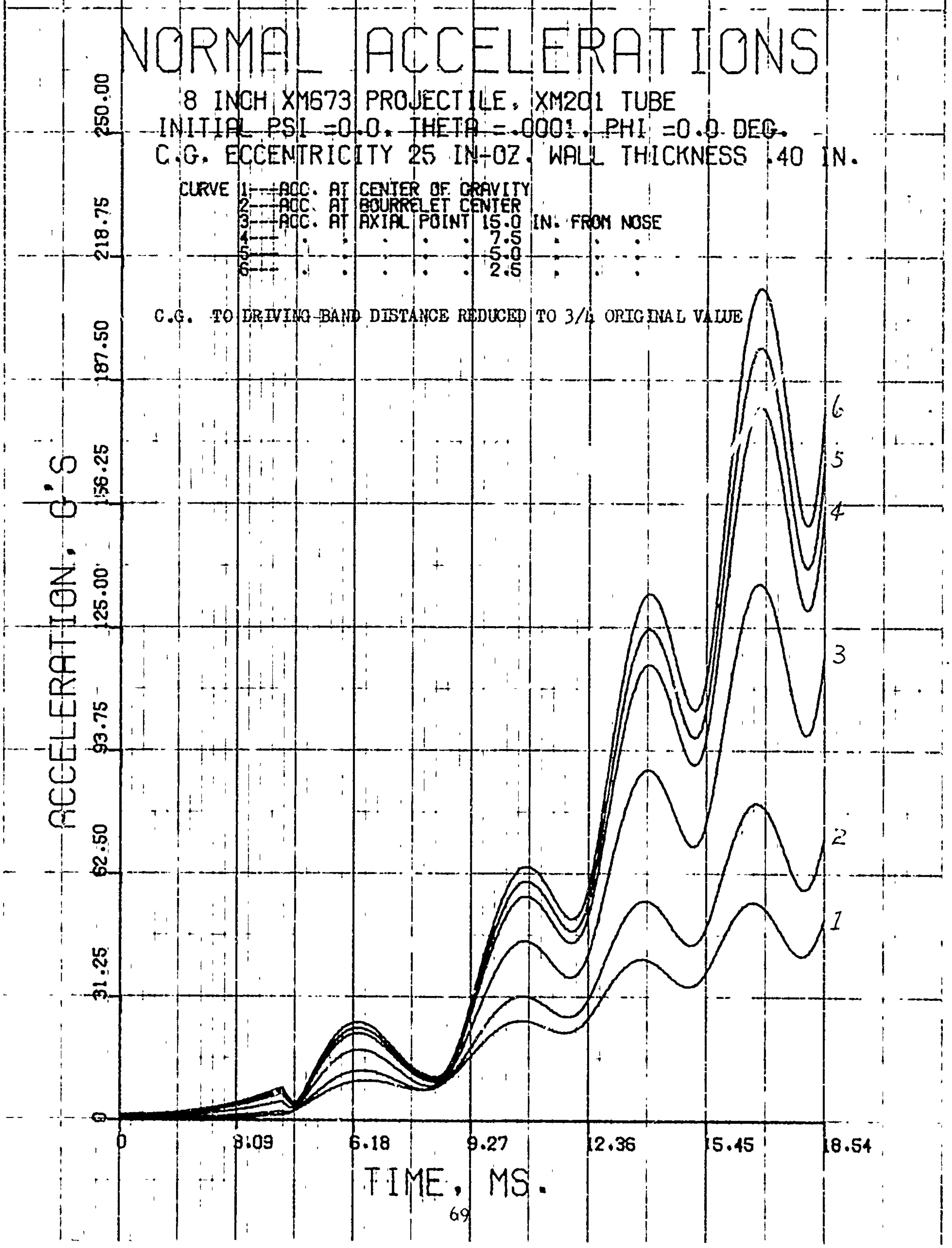

NORMAL ACCELERATIONS
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ, WALL THICKNESS .40 IN.
CURVE 1---ACC. AT CENTER OF GRAVITY
2---ACC. AT BOURRELET CENTER
3---ACC. AT AXIAL POINT 15.0 IN. FROM NOSE
4--- . . . . . 7.5 . . .
5--- . . . . . 5.0 . . .
6--- . . . . . 2.5 . . .
C.G. TO DRIVING BAND DISTANCE REDUCED TO 3/4 ORIGINAL VALUE
ACCELERATION, G'S
250.00
218.75
187.50
156.25
125.00
93.75
62.50
31.25
0
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.
6
5
4
3
2
1

FIGURE 19b

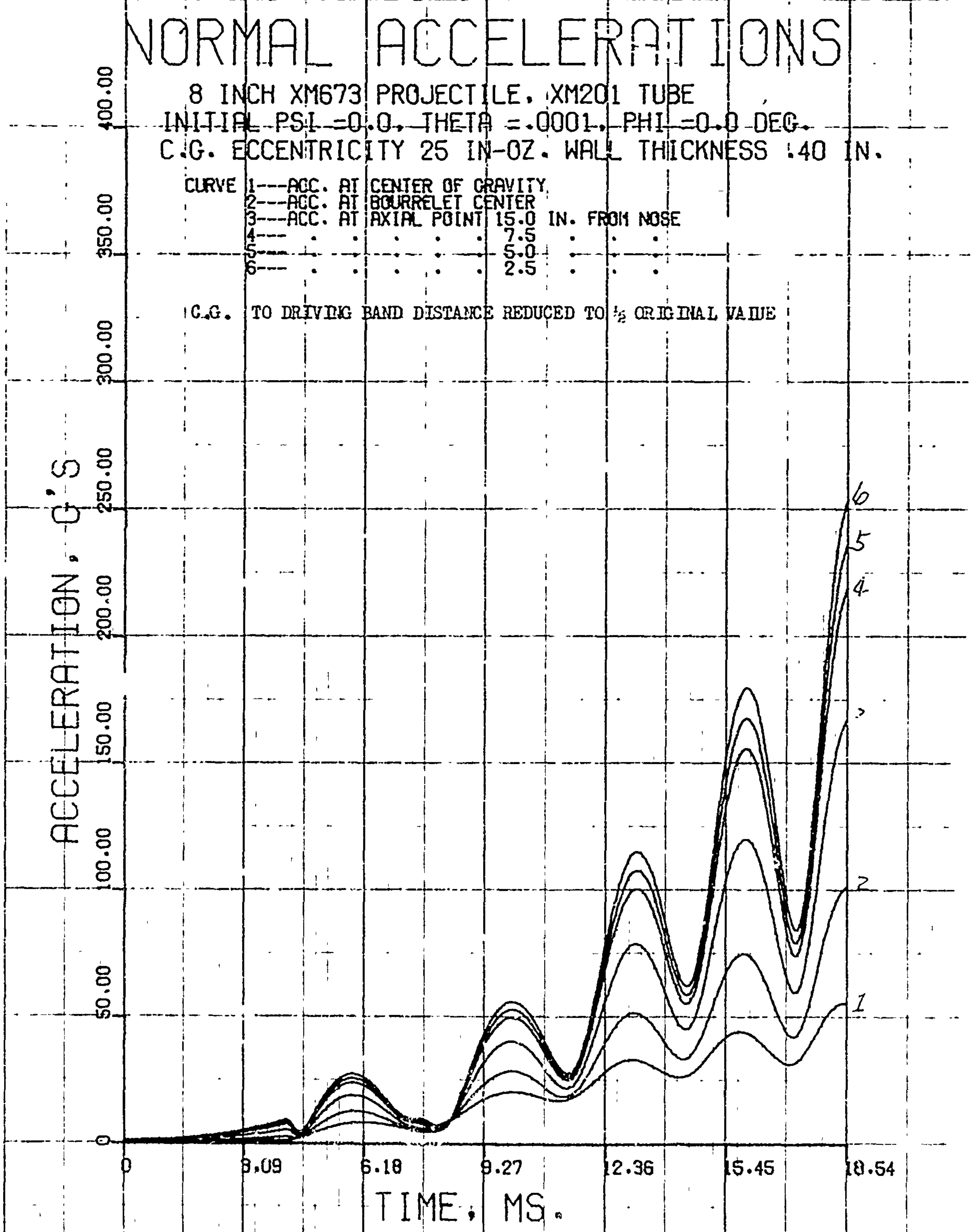
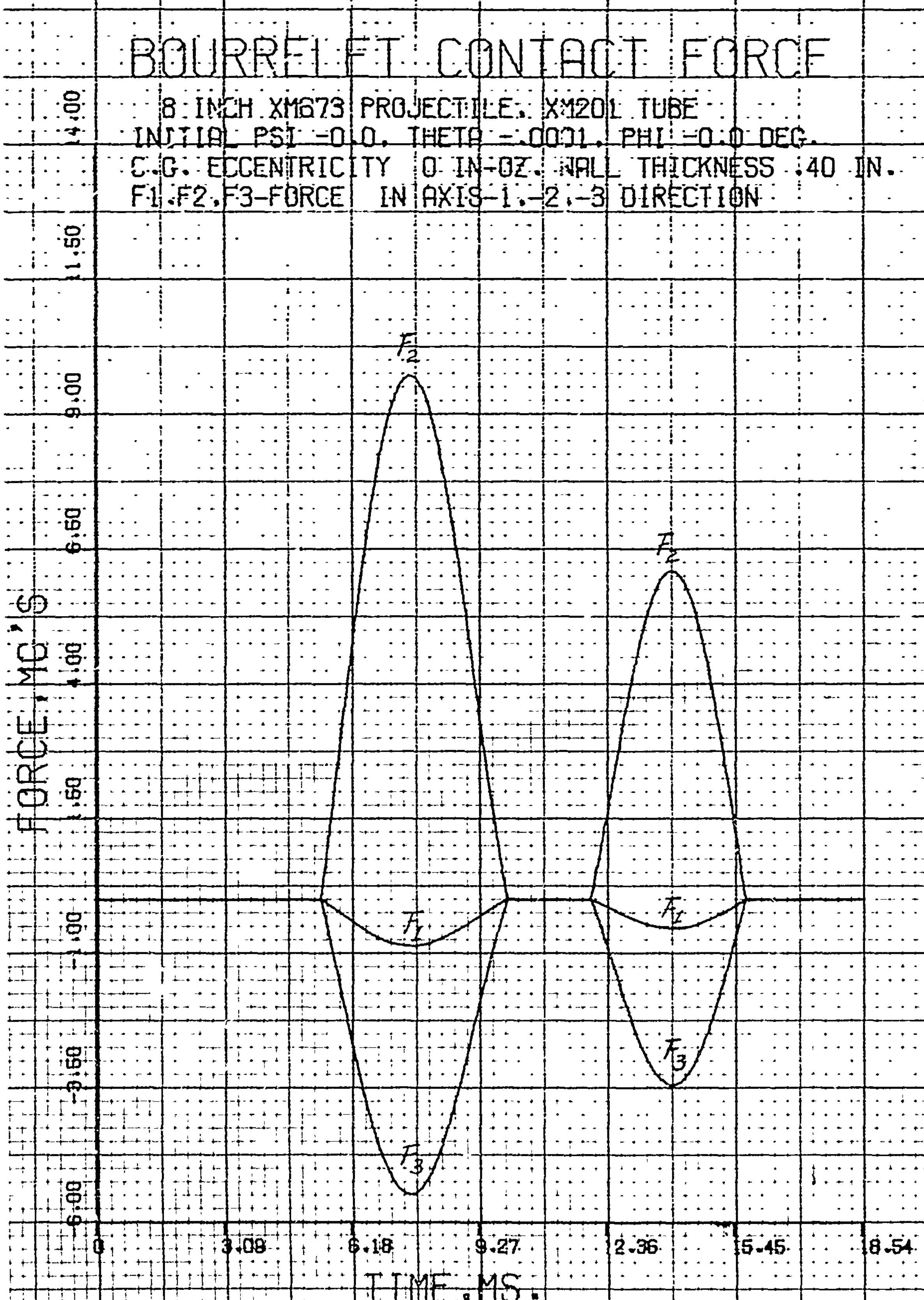

NORMAL ACCELERATIONS
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .40 IN.
CURVE 1---ACC. AT CENTER OF GRAVITY
2---ACC. AT BOURRELET CENTER
3---ACC. AT AXIAL POINT 15.0 IN. FROM NOSE
4--- " " " " 7.5 " " "
5--- " " " " 5.0 " " "
6--- " " " " 2.5 " " "
C.G. TO DRIVING BAND DISTANCE REDUCED TO ½ ORIGINAL VALUE
ACCELERATION, G'S
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.
6
5
4
3
2
1

FIGURE 20a



BOURRELET CONTACT FORCE
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ. WALL THICKNESS .40 IN.
F1,F2,F3-FORCE IN AXIS-1,-2,-3 DIRECTION
FORCE,MC'S
14.00
11.50
9.00
6.50
4.00
1.50
-1.00
-3.50
-6.00
F2
F1
F3
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME,MS.

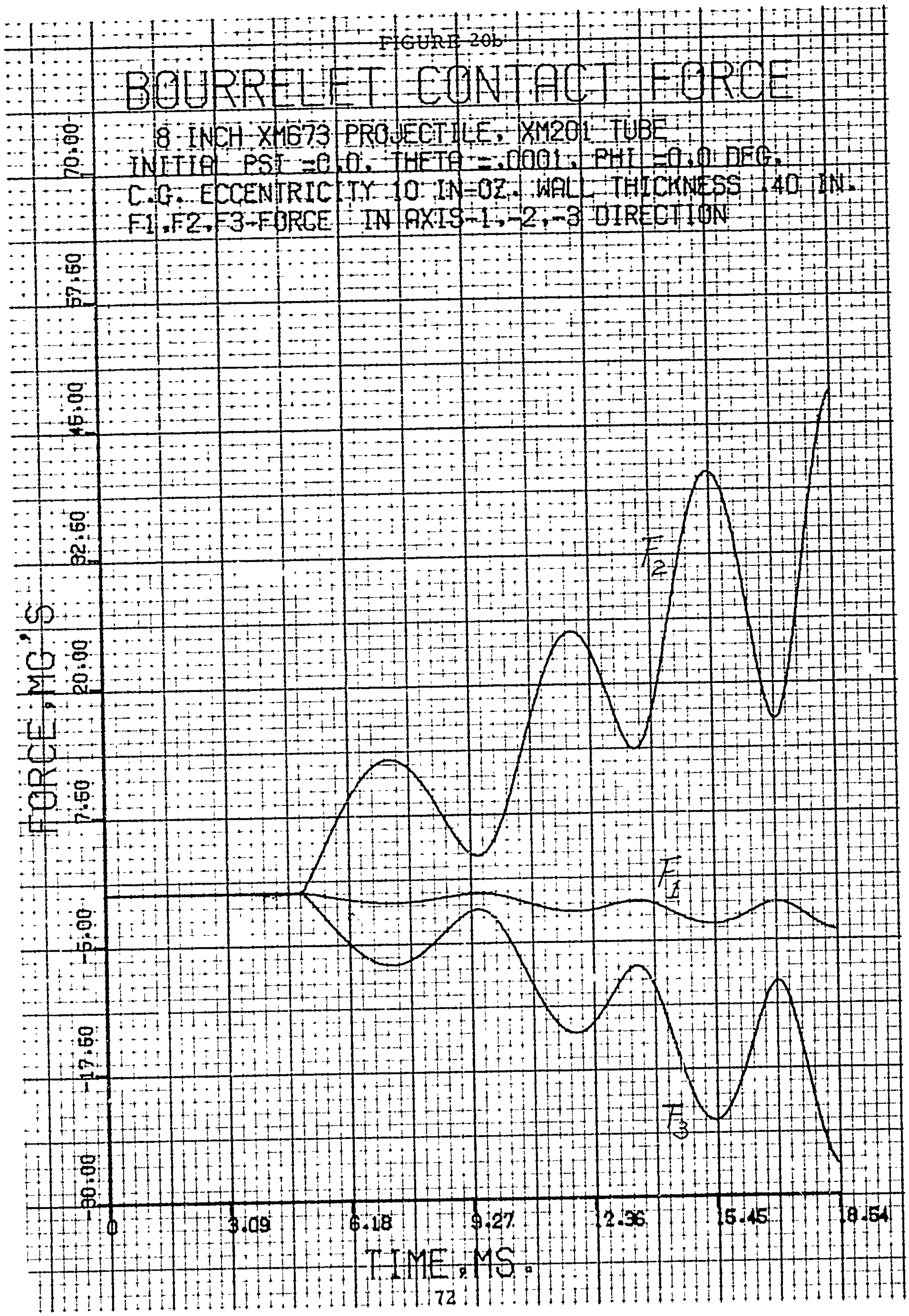

BOURRELET CONTACT FORCE
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ. WALL THICKNESS .40 IN.
F1,F2,F3-FORCE IN AXIS-1,-2,-3 DIRECTION
FORCE, MG'S
70.00
57.50
45.00
32.50
20.00
7.50
-5.00
-17.50
-30.00
TIME, MS.
0
3.09
6.18
9.27
12.36
15.45
18.54
F_2
F_1
F_3

FIGURE 20b

FIGURE 20c

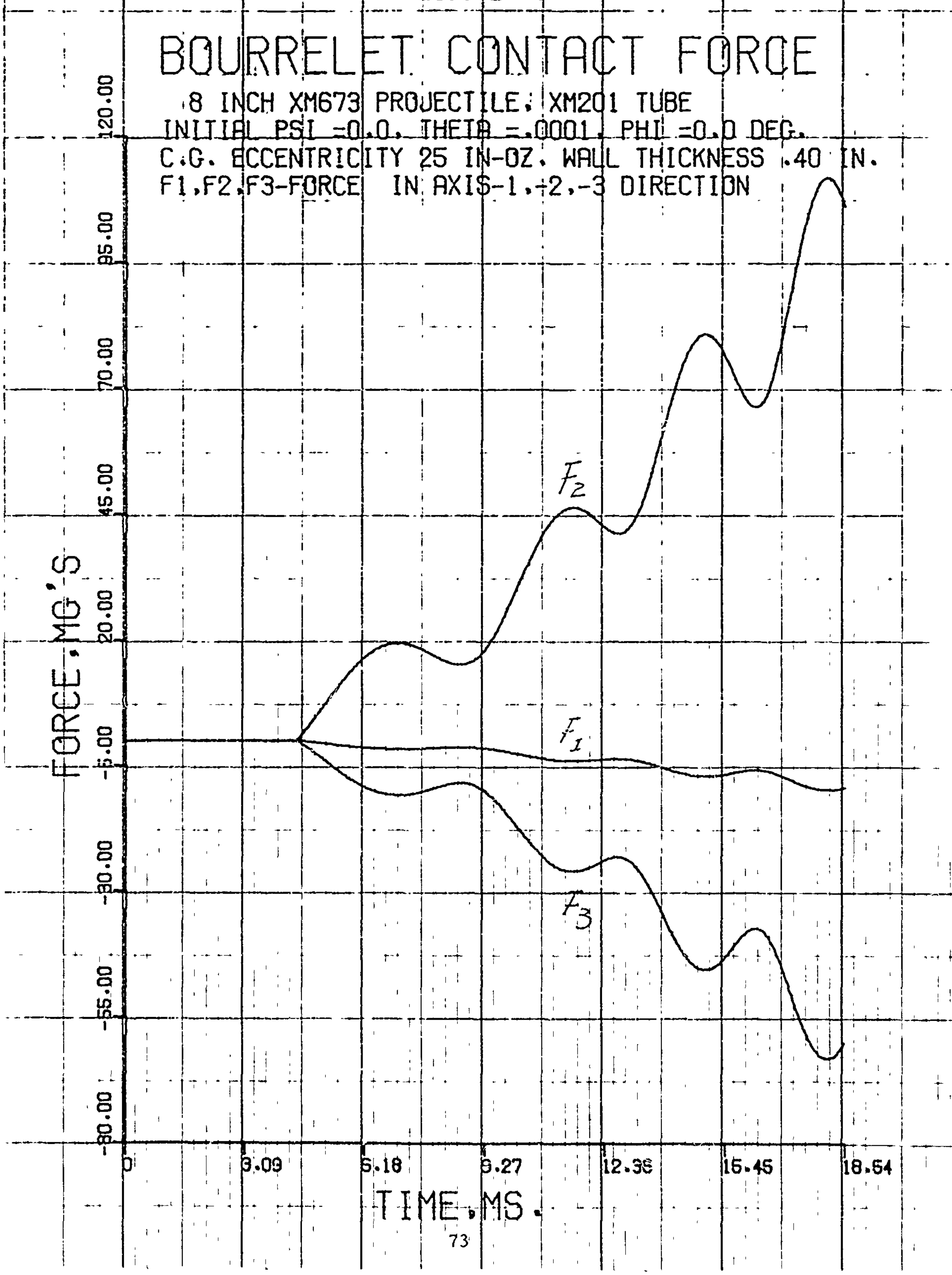

BOURRELET CONTACT FORCE
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ, WALL THICKNESS .40 IN.
F1,F2,F3-FORCE IN AXIS-1,-2,-3 DIRECTION
FORCE,MG'S
120.00
95.00
70.00
45.00
20.00
-5.00
-30.00
-55.00
-80.00
TIME,MS.
0
3.09
6.18
9.27
12.36
15.45
18.54
F2
F1
F3

FIGURE 20d

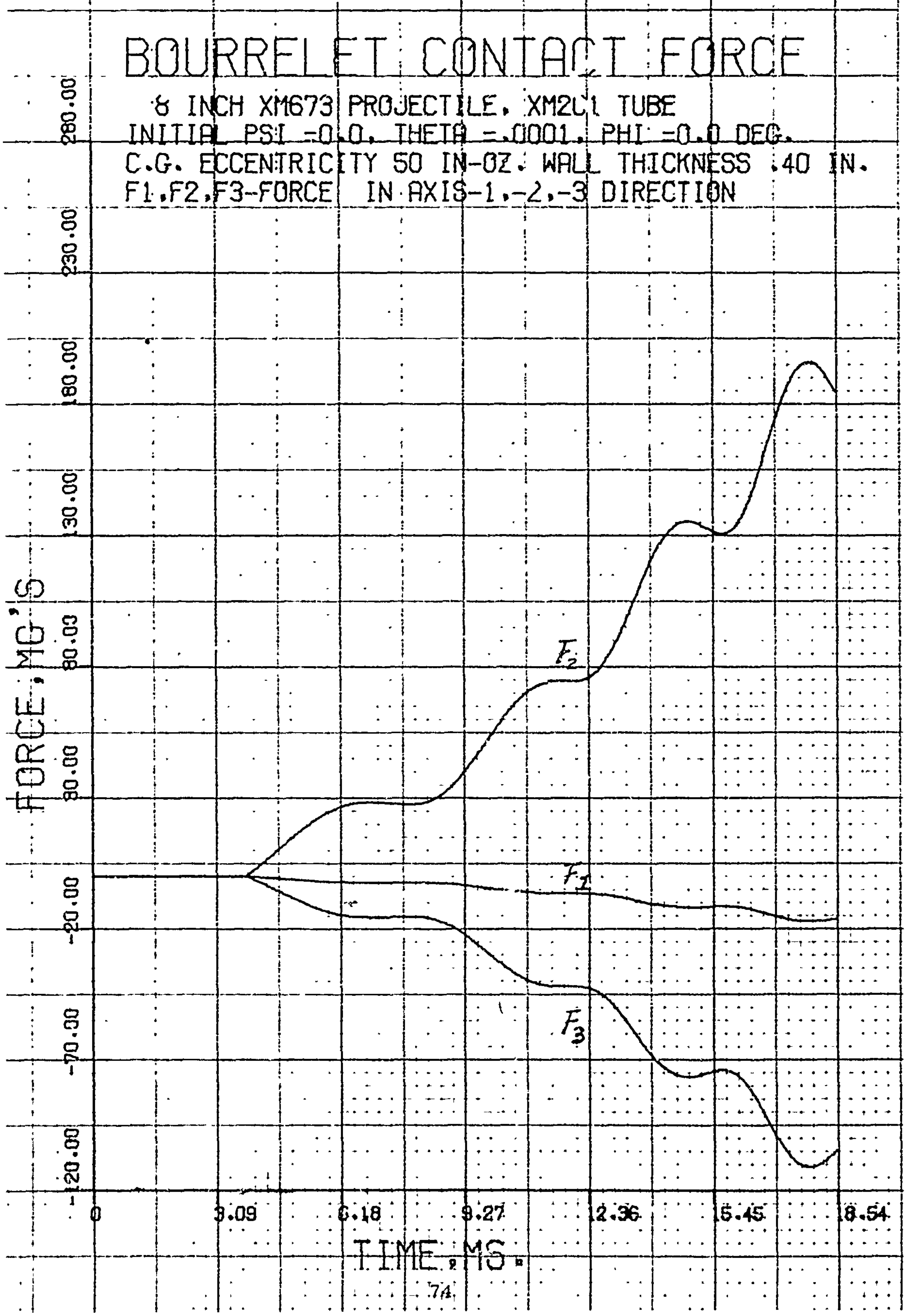

BOURRELET CONTACT FORCE
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ. WALL THICKNESS .40 IN.
F1,F2,F3-FORCE IN AXIS-1,-2,-3 DIRECTION
FORCE, MG'S
280.00
230.00
180.00
130.00
80.00
30.00
-20.00
-70.00
-120.00
TIME, MS.
0
3.09
6.18
9.27
12.36
15.45
18.54
F2
F1
F3

FIGURE 21a

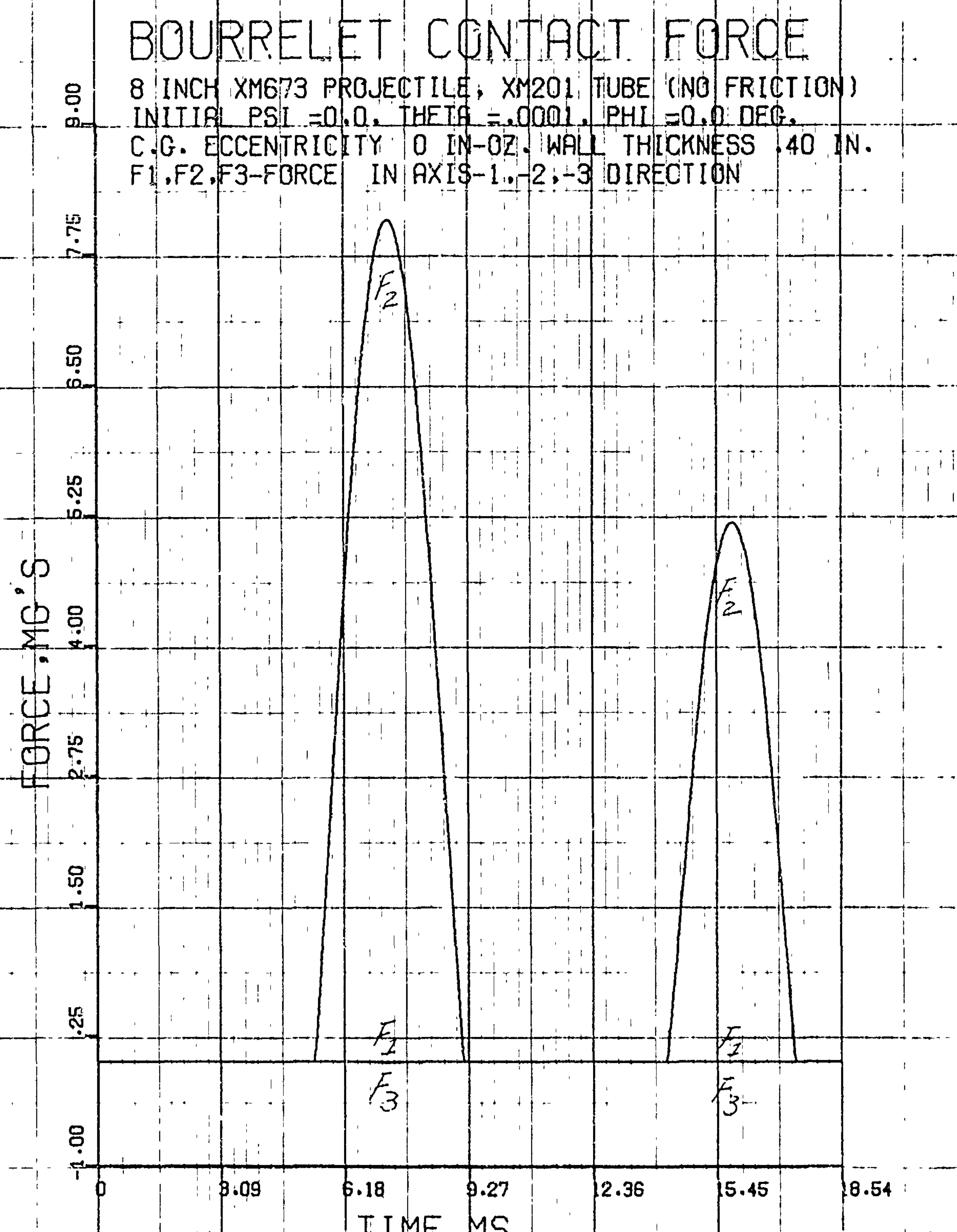

BOURRELET CONTACT FORCE
8 INCH XM673 PROJECTILE, XM201 TUBE (NO FRICTION)
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ. WALL THICKNESS .40 IN.
F1,F2,F3-FORCE IN AXIS-1,-2,-3 DIRECTION
FORCE, MG'S
9.00
7.75
6.50
5.25
4.00
2.75
1.50
.25
-1.00
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.
F2
F2
F1
F1
F3
F3

FIGURE 21b

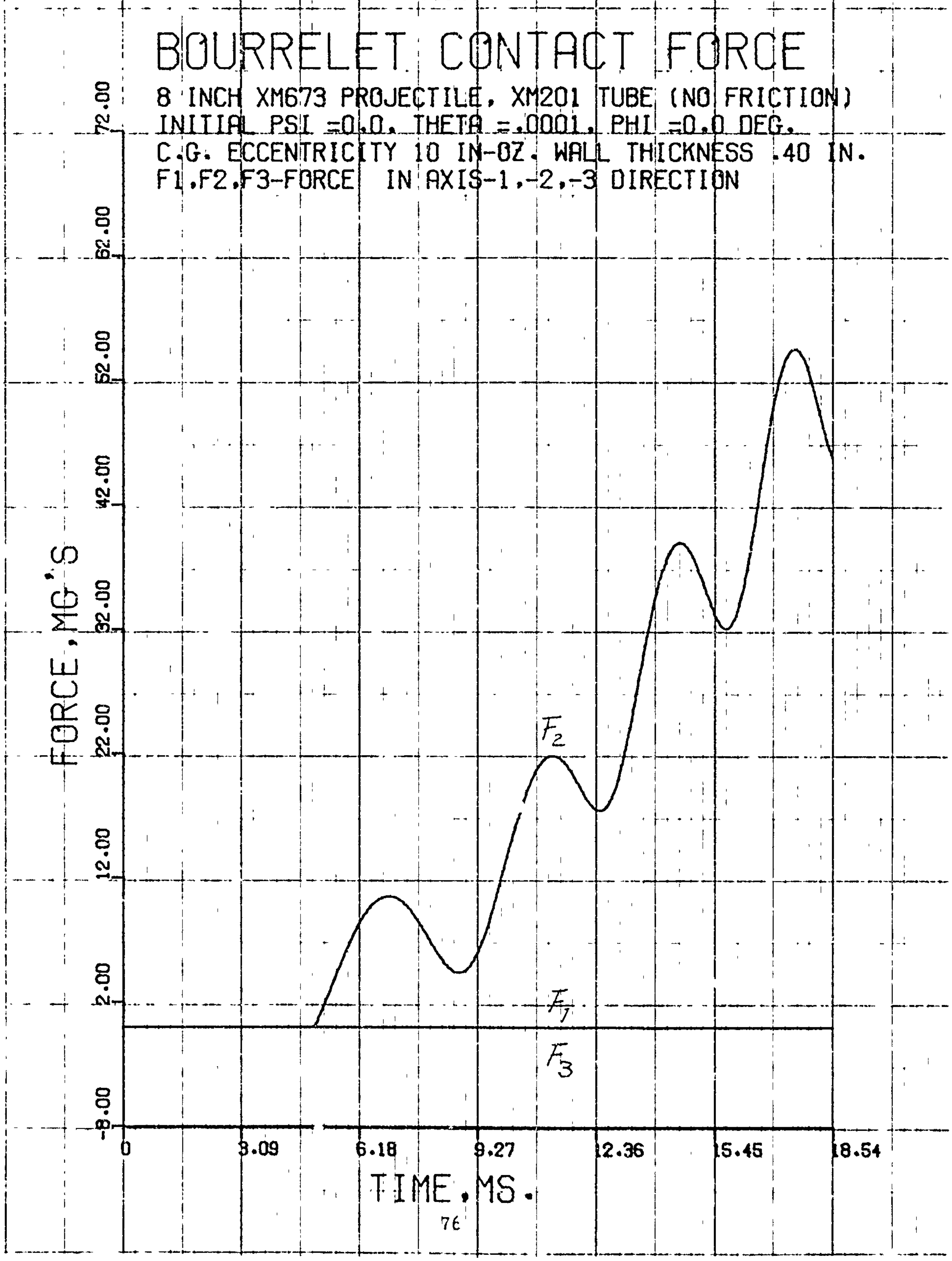

BOURRELET CONTACT FORCE
8 INCH XM673 PROJECTILE, XM201 TUBE (NO FRICTION)
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ. WALL THICKNESS .40 IN.
F1,F2,F3-FORCE IN AXIS-1,-2,-3 DIRECTION
FORCE, MG'S
72.00
62.00
52.00
42.00
32.00
22.00
12.00
2.00
-8.00
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.
F_2
F_1
F_3

FIGURE 21c

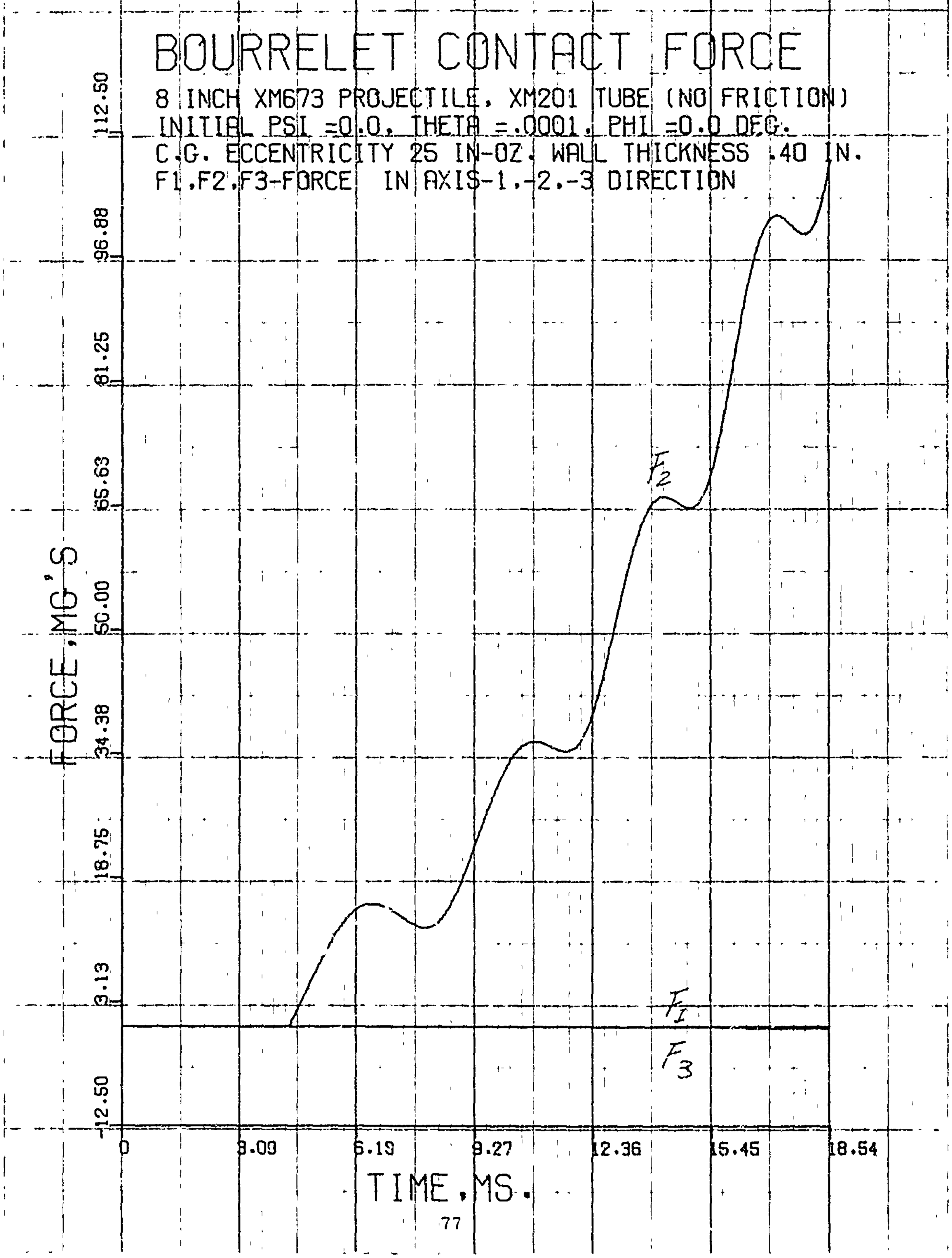

BOURRELET CONTACT FORCE
8 INCH XM673 PROJECTILE, XM201 TUBE (NO FRICTION)
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .40 IN.
F1,F2,F3-FORCE IN AXIS-1,-2,-3 DIRECTION
FORCE, MG'S
112.50
96.88
81.25
65.63
50.00
34.38
18.75
3.13
-12.50
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.
F2
F1
F3

FIGURE 21d

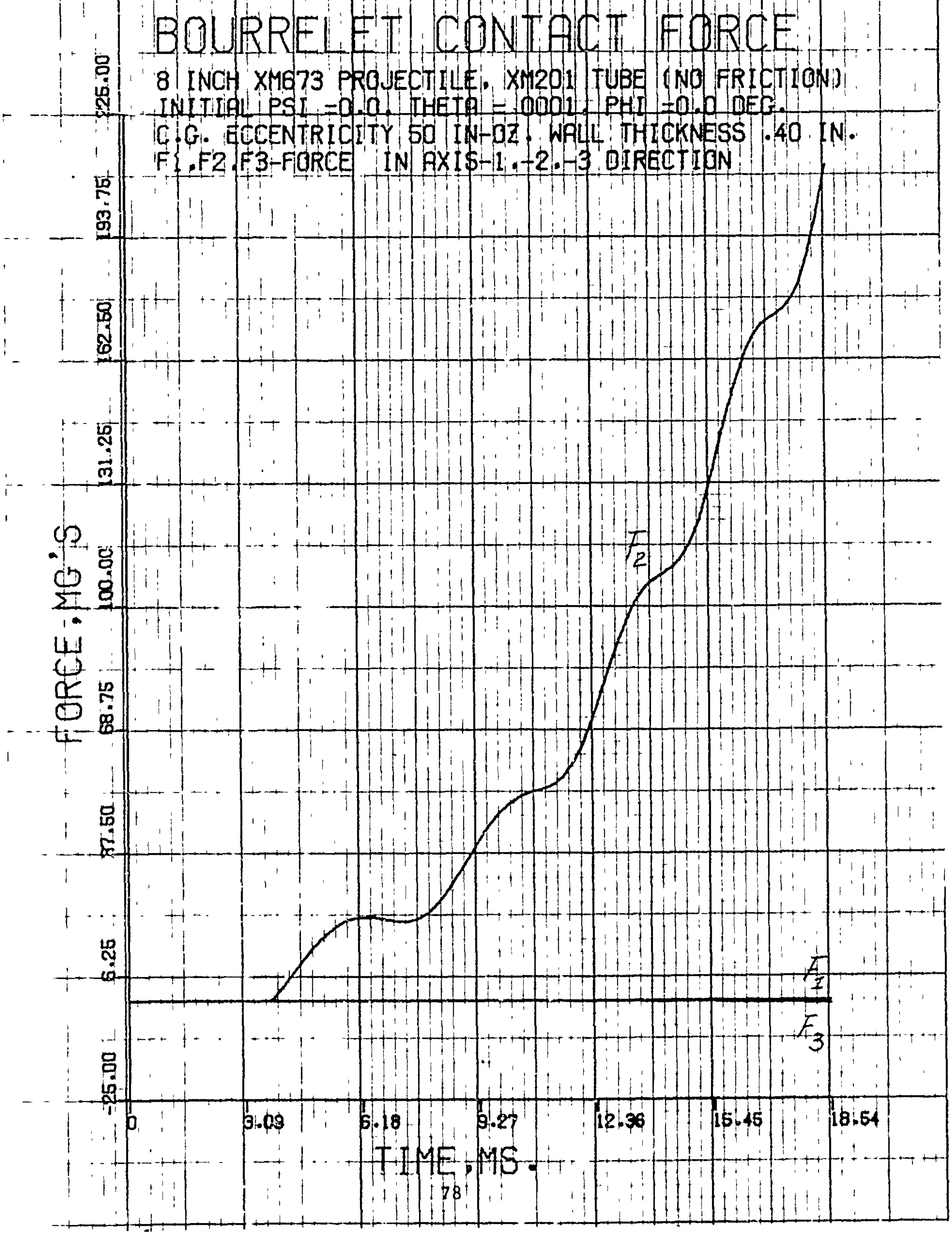

BOURRELET CONTACT FORCE
8 INCH XM673 PROJECTILE. XM201 TUBE (NO FRICTION)
INITIAL PSI =0.0. THETA = .0001. PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ. WALL THICKNESS .40 IN.
F1.F2.F3-FORCE IN AXIS-1.-2.-3 DIRECTION
FORCE, MG'S
225.00
193.75
162.50
131.25
100.00
68.75
37.50
6.25
-25.00
TIME, MS.
0
3.09
6.18
9.27
12.36
15.45
18.54
F2
F1
F3

FIGURE 22a

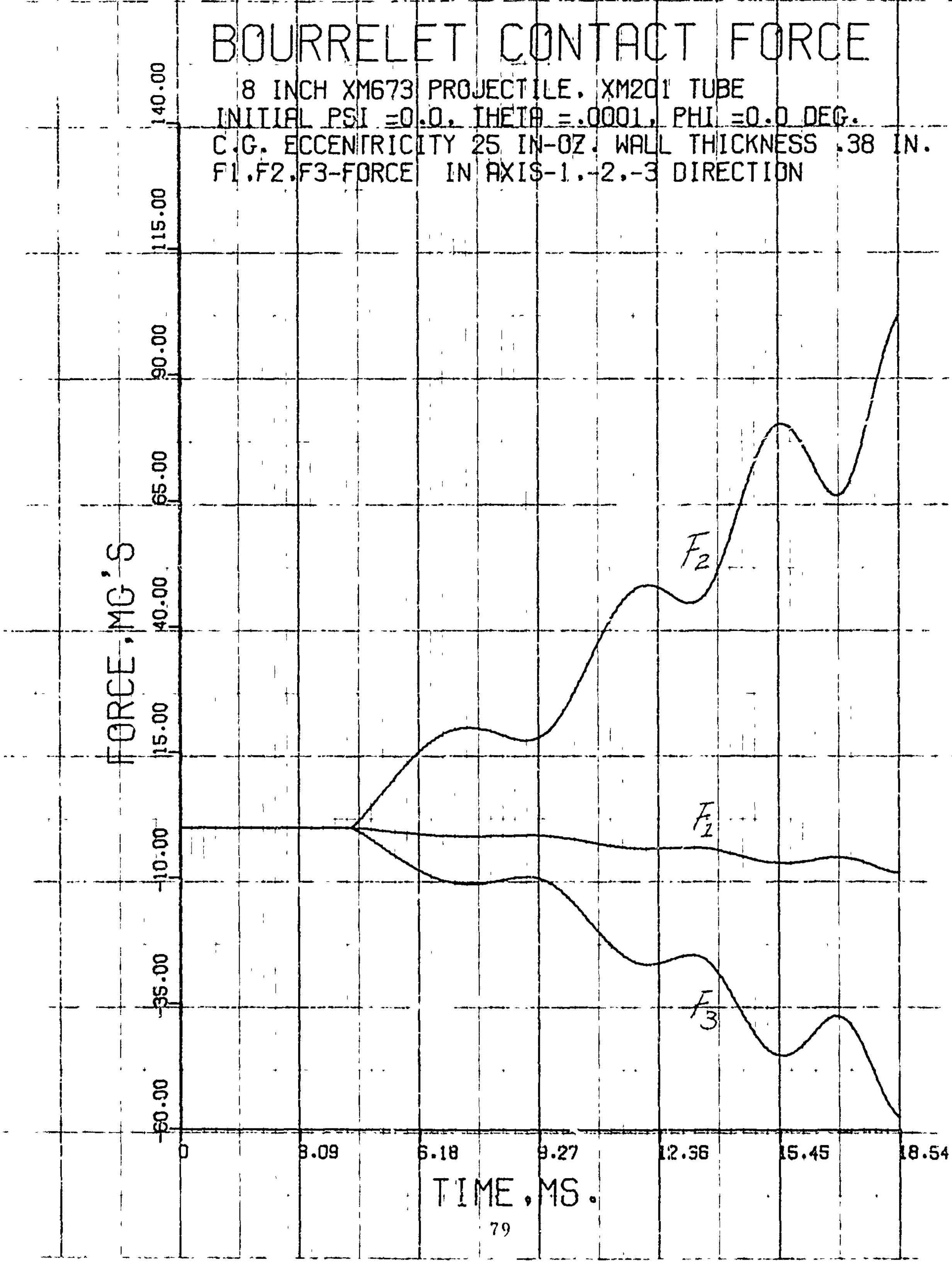

BOURRELET CONTACT FORCE
8 INCH XM673 PROJECTILE. XM201 TUBE
INITIAL PSI =0.0. THETA =.0001. PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .38 IN.
F1.F2.F3-FORCE IN AXIS-1.-2.-3 DIRECTION
FORCE,MG'S
140.00
115.00
90.00
65.00
40.00
15.00
-10.00
-35.00
-60.00
TIME,MS.
0
3.09
6.18
9.27
12.36
15.45
18.54
F2
F1
F3

FIGURE 22b

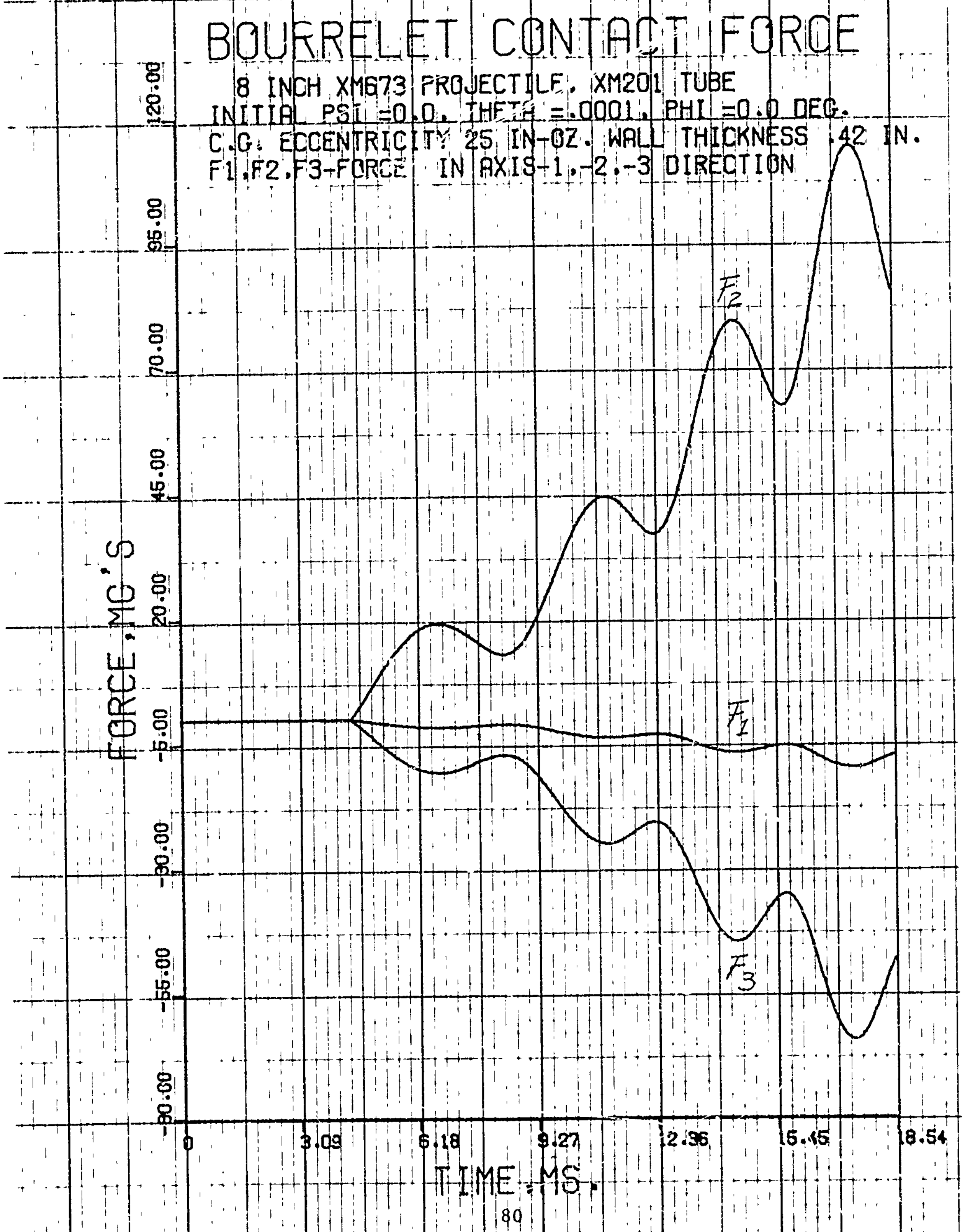

BOURRELET CONTACT FORCE
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .42 IN.
F1,F2,F3-FORCE IN AXIS-1,-2,-3 DIRECTION
FORCE,MC'S
120.00
95.00
70.00
45.00
20.00
-5.00
-30.00
-55.00
-80.00
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME,MS.
F2
F1
F3

FIGURE 23a

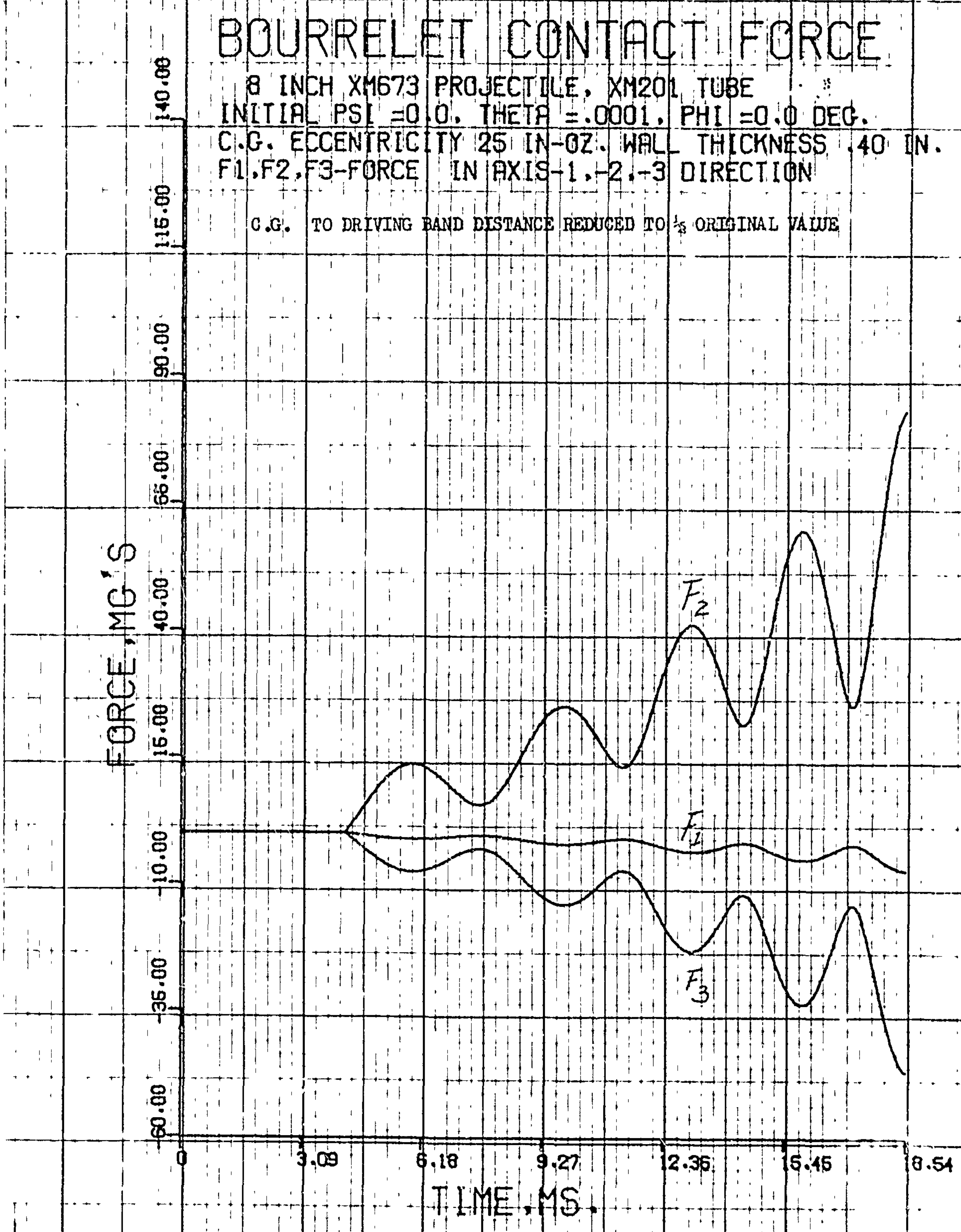
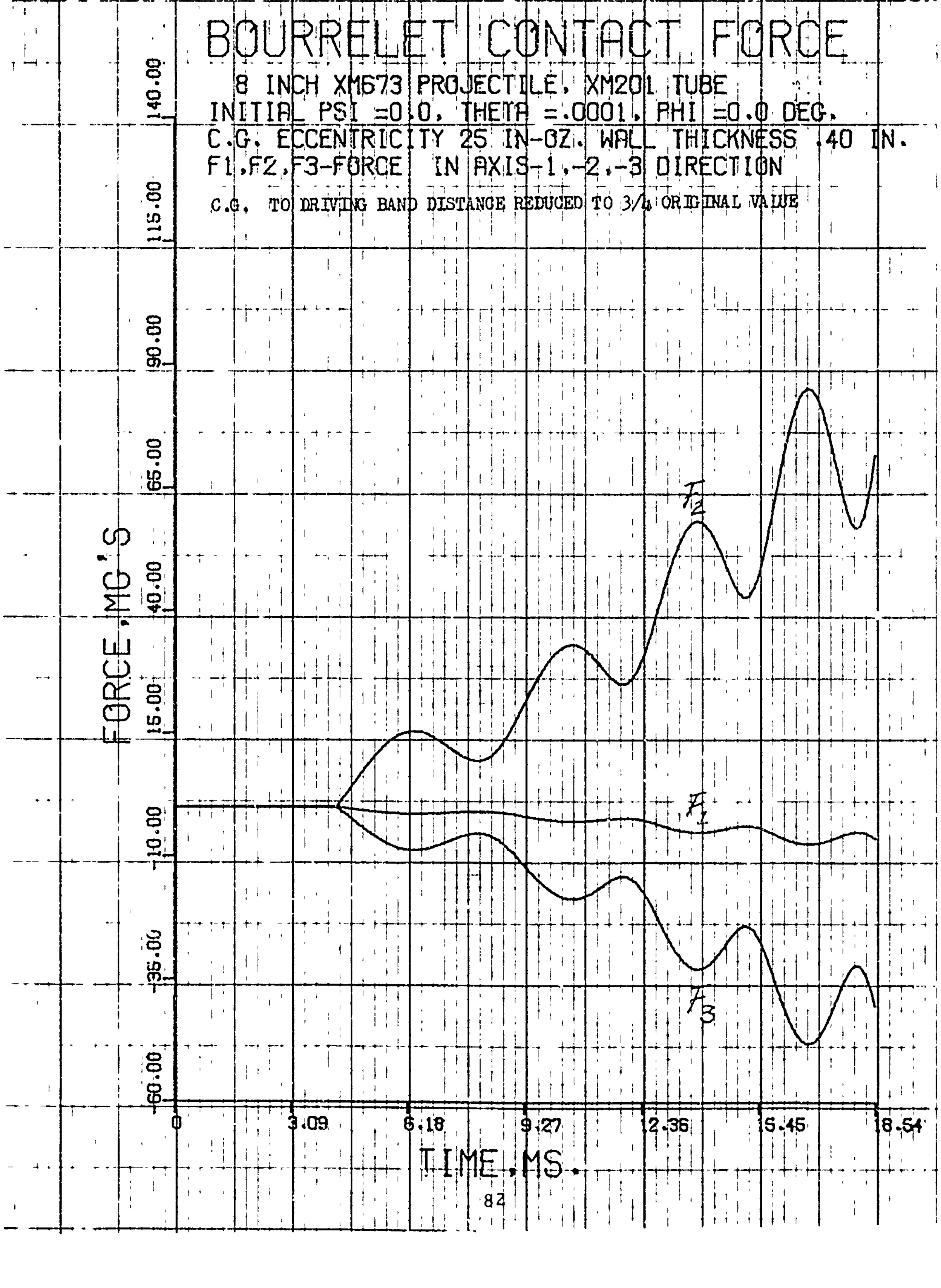
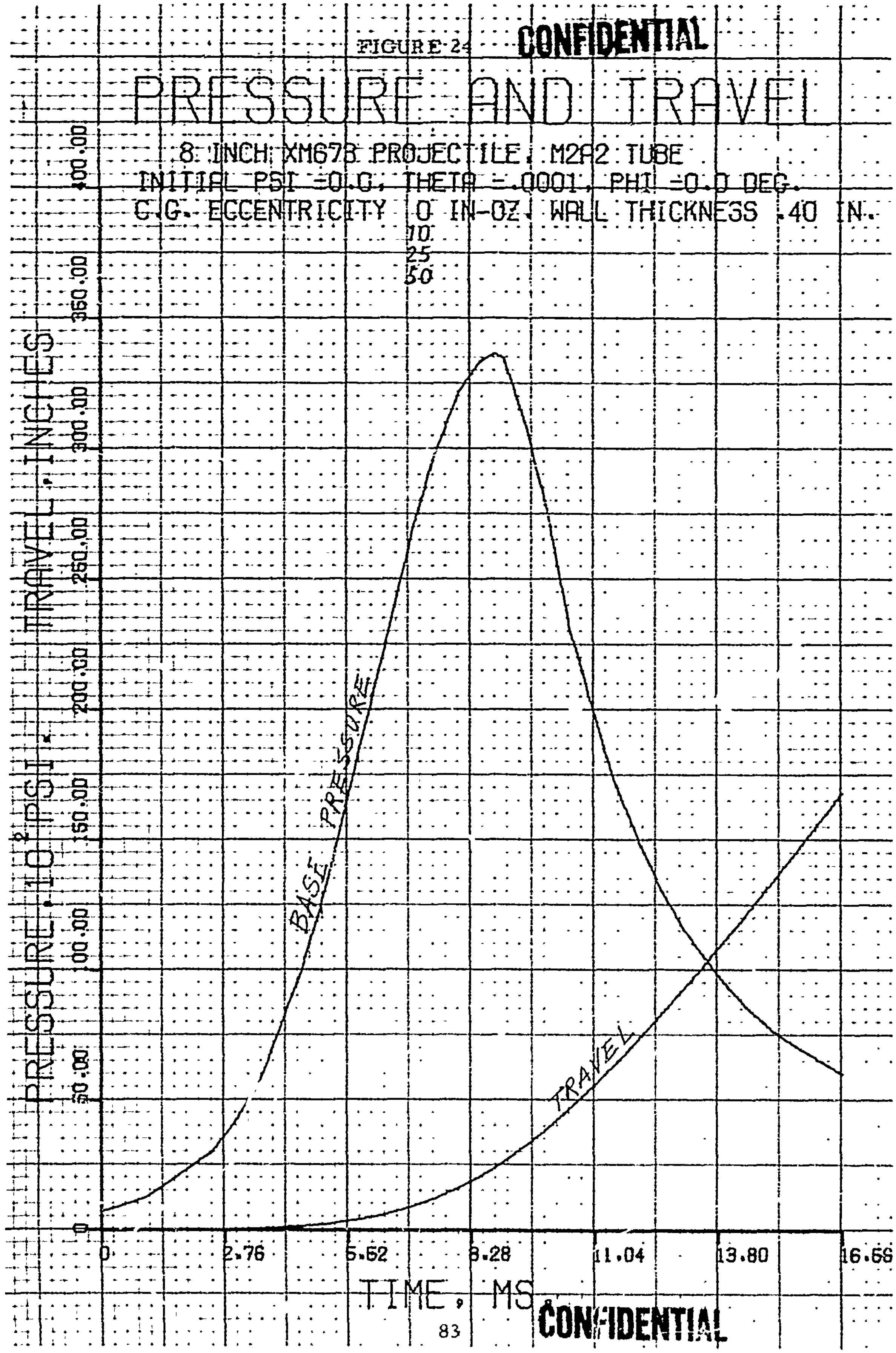

BOURRELET CONTACT FORCE
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .40 IN.
F1,F2,F3-FORCE IN AXIS-1,-2,-3 DIRECTION
C.G. TO DRIVING BAND DISTANCE REDUCED TO ⅓ ORIGINAL VALUE
FORCE, MG'S
140.00
115.00
90.00
65.00
40.00
15.00
-10.00
-35.00
-60.00
F_2
F_1
F_3
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.

FIGURE 23b


BOURRELET CONTACT FORCE
8 INCH XM673 PROJECTILE, XM201 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .40 IN.
F1,F2,F3-FORCE IN AXIS-1,-2,-3 DIRECTION
C.G. TO DRIVING BAND DISTANCE REDUCED TO 3/4 ORIGINAL VALUE
FORCE, MC'S
140.00
115.00
90.00
65.00
40.00
15.00
-10.00
-35.00
-60.00
F2
F1
F3
0
3.09
6.18
9.27
12.36
15.45
18.54
TIME, MS.

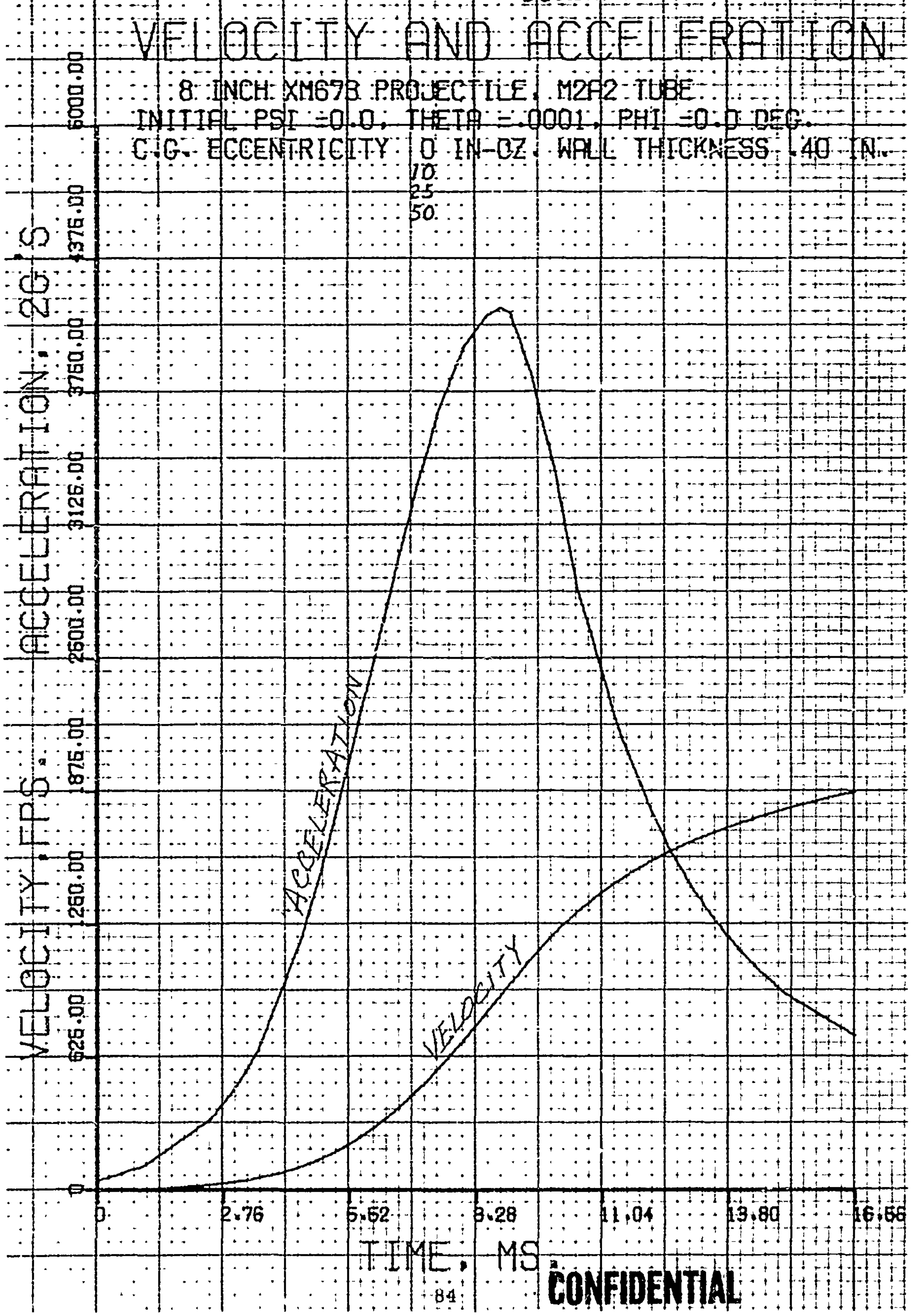
M2A2 TUBE

FIGURE 24 CONFIDENTIAL



CONFIDENTIAL

FIGURE 25 **CONFIDENTIAL**

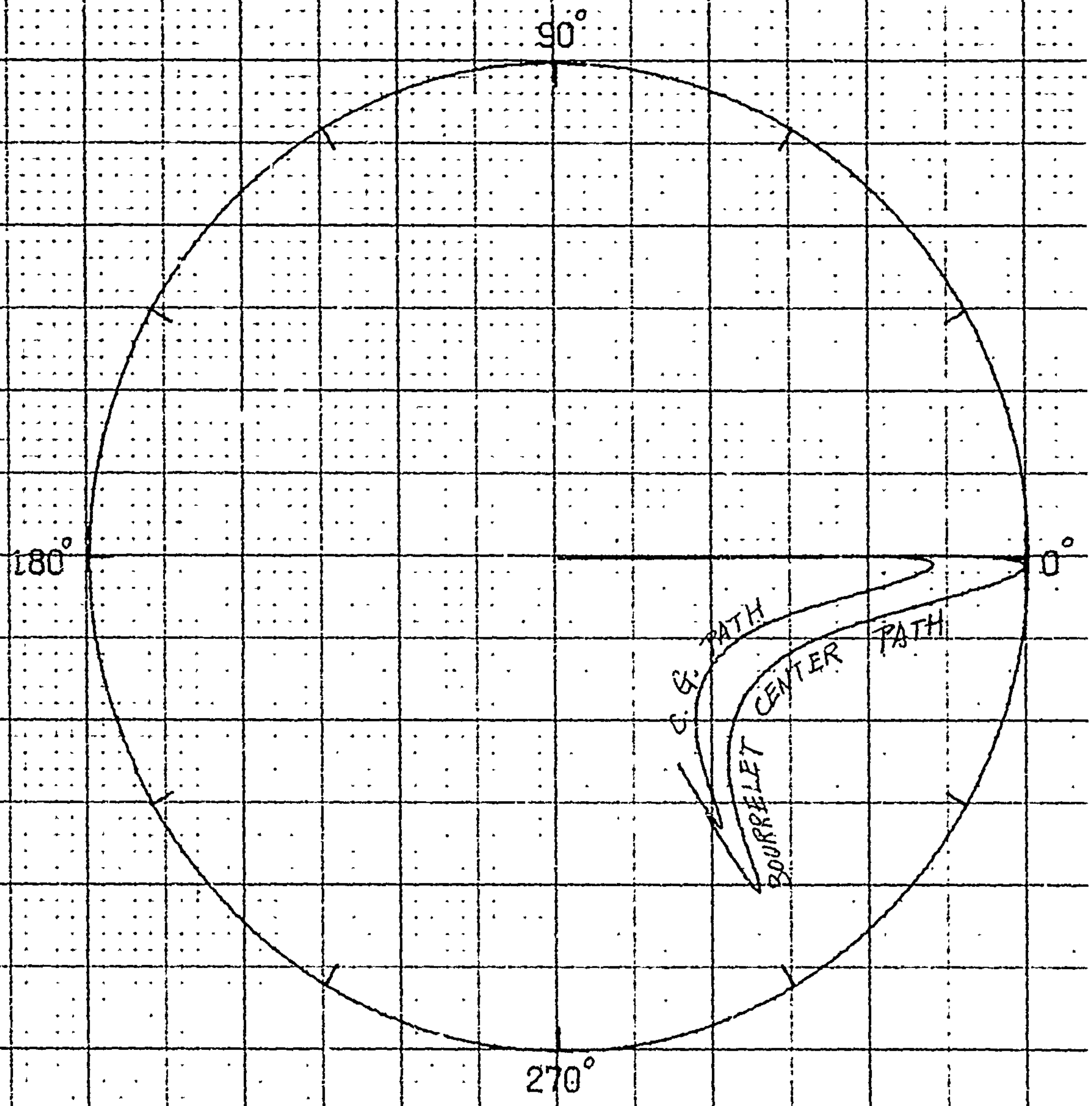


CONFIDENTIAL

FIGURE 26a

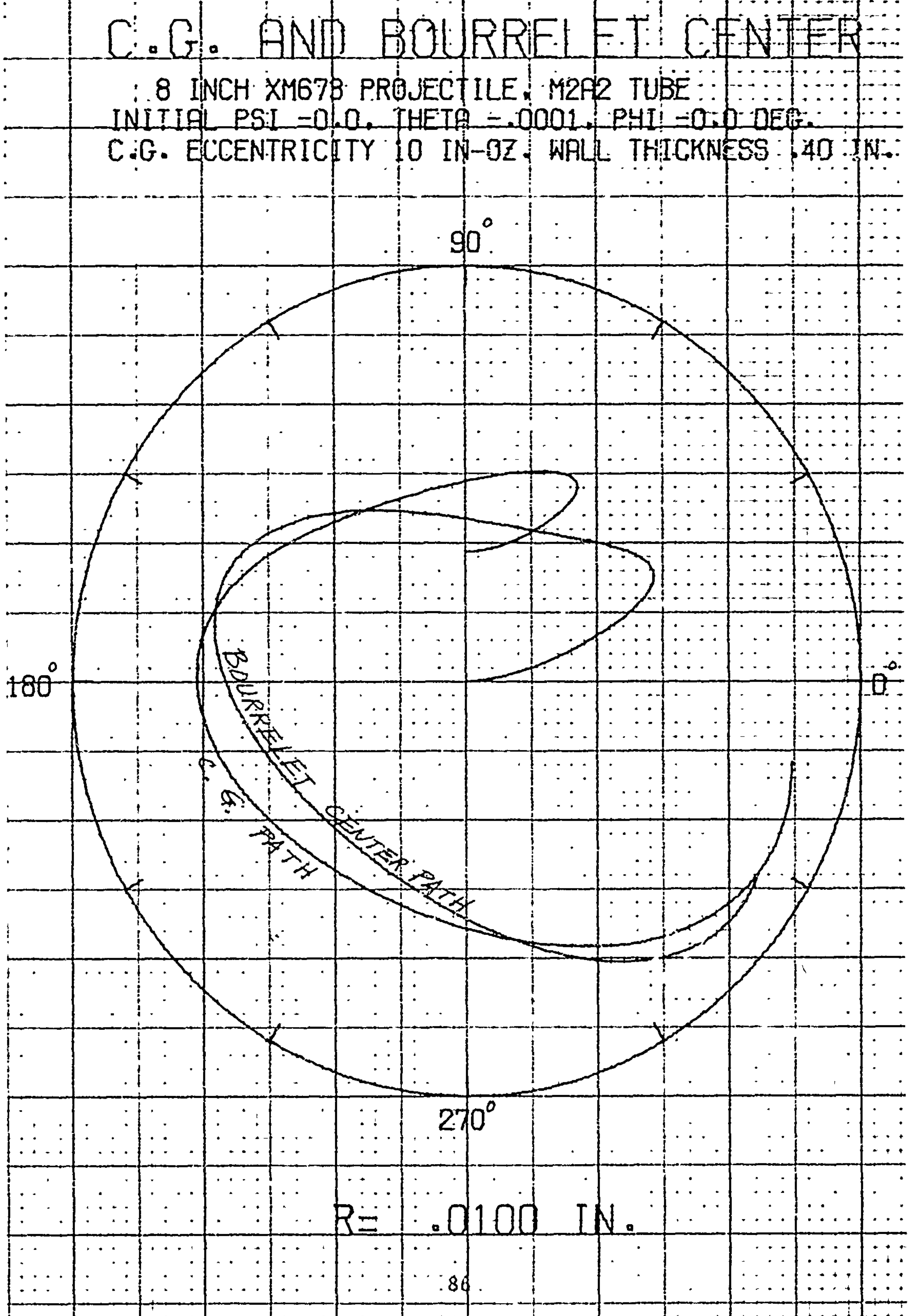
C.G. AND BOURRELET CENTER

8 INCH XM673 PROJECTILE, M2A2 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ, WALL THICKNESS .40 IN.



R= .0050 IN.

FIGURE 26b



C.G. AND BOURRELET CENTER
8 INCH XM678 PROJECTILE, M2A2 TUBE
INITIAL PSI -0.0, THETA -.0001, PHI -0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ, WALL THICKNESS .40 IN.
90°
180°
0°
270°
BOURRELET CENTER PATH
C. G. PATH
R= .0100 IN.

FIGURE 26c

C.G. AND BOURRELET CENTER

8 INCH XM673 PROJECTILE, M2A2 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ, WALL THICKNESS .40 IN.

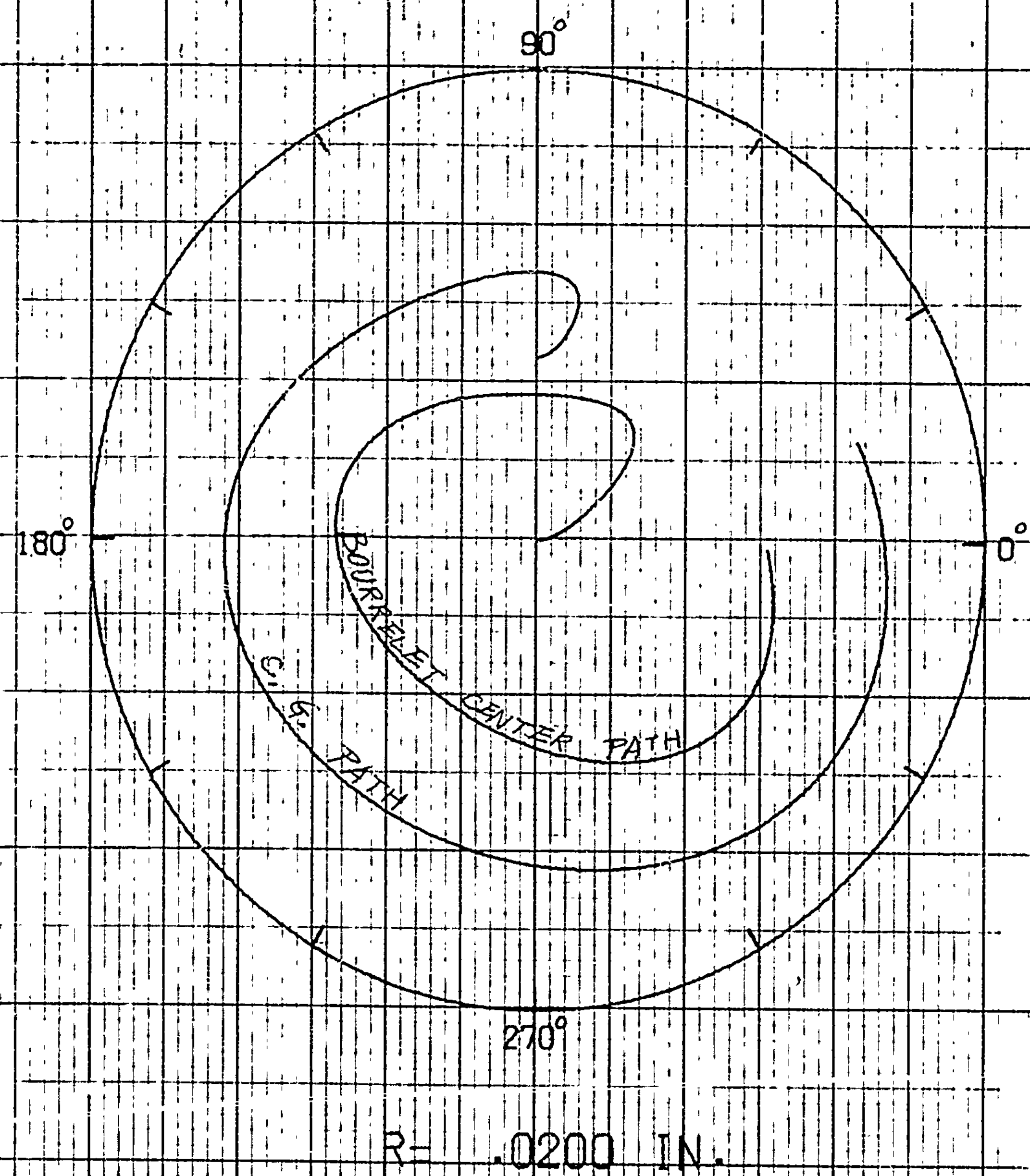
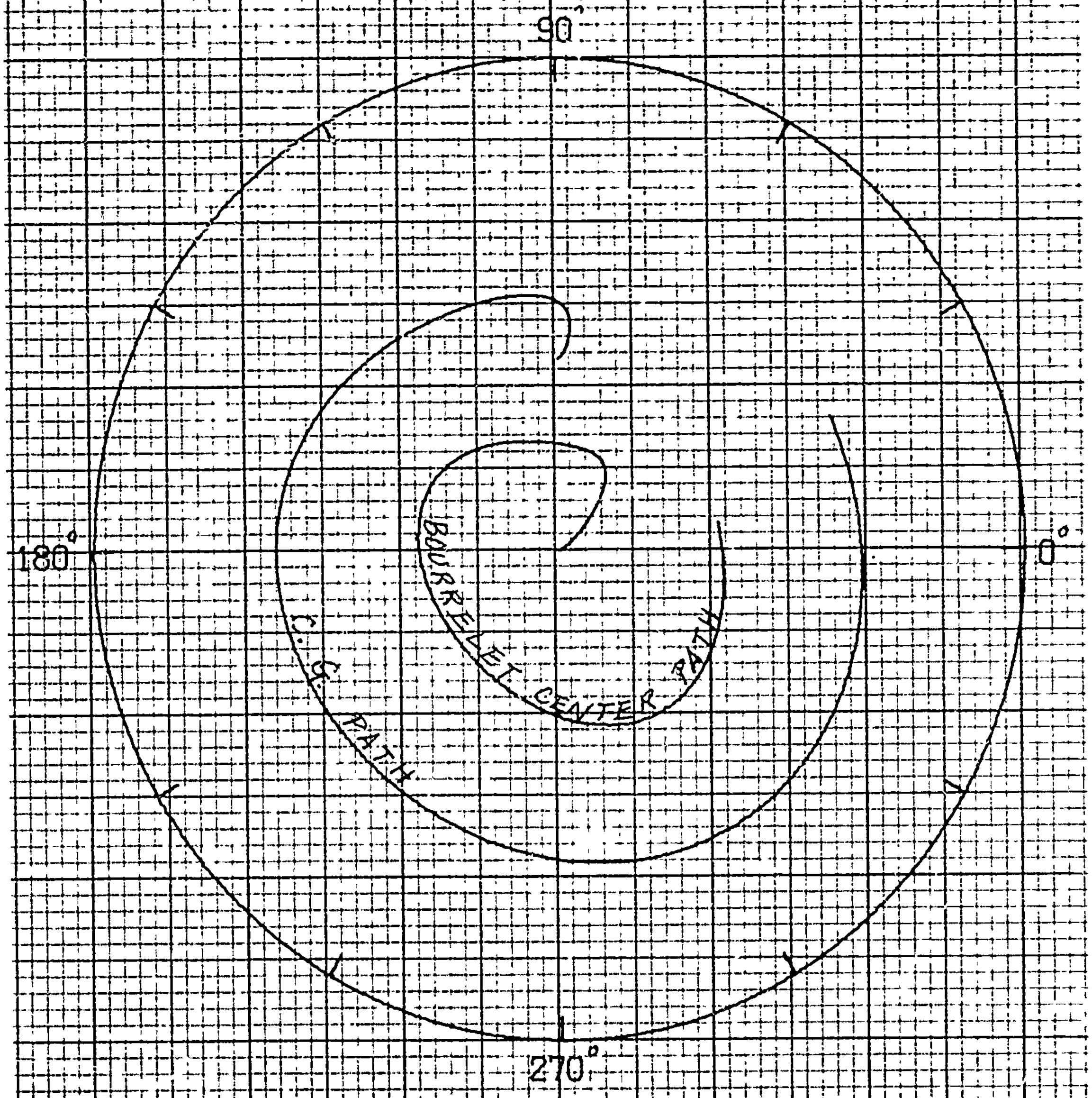


FIGURE 26d

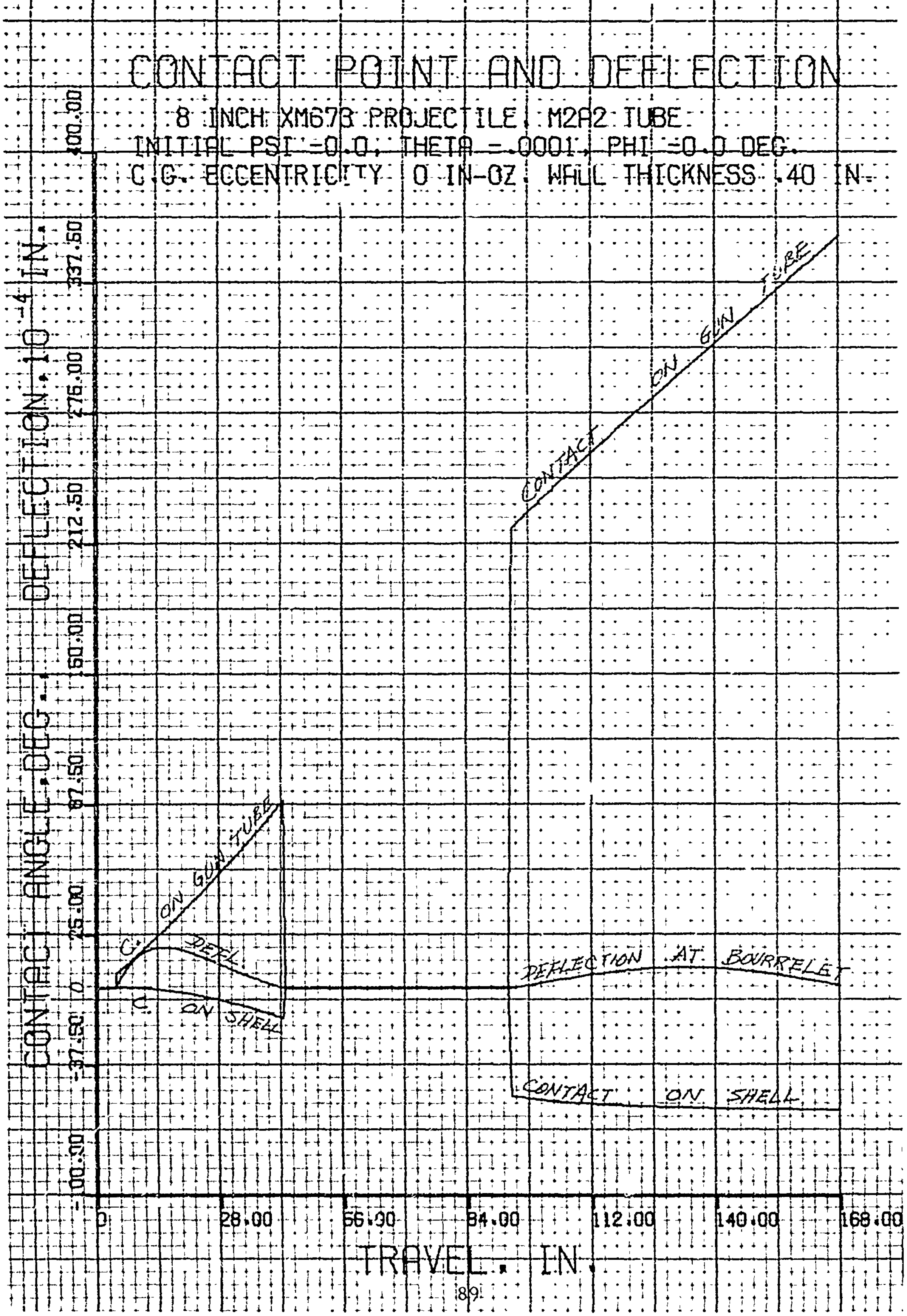
C.G. AND BOURRELET CENTER

8 INCH XM673 PROJECTILE, M2A2 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ, WALL THICKNESS .40 IN.



R= .0400 IN.

FIGURE 27a



CONTACT POINT AND DEFLECTION
8 INCH XM673 PROJECTILE, M2A2 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ, WALL THICKNESS .40 IN.
CONTACT ANGLE, DEG.; DEFLECTION, 10 -4 IN.
400.00
337.50
275.00
212.50
150.00
87.50
25.00
0
-37.50
-100.00
0
28.00
56.00
84.00
112.00
140.00
168.00
TRAVEL, IN.
CONTACT ON GUN TUBE
C. ON GUN TUBE
DEFL.
C. ON SHELL
DEFLECTION AT BOURRELET
CONTACT ON SHELL

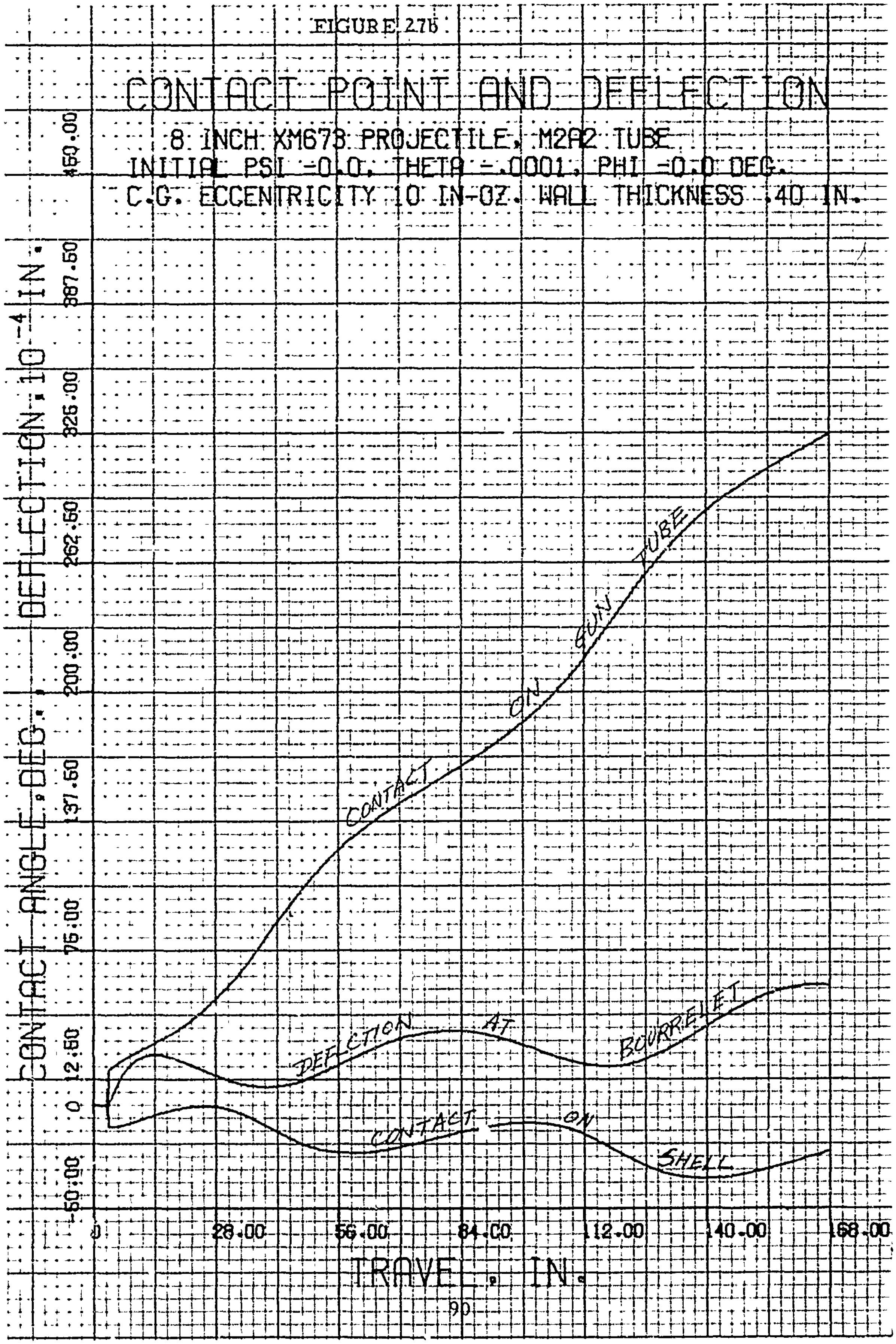


FIGURE 27b
CONTACT POINT AND DEFLECTION
8 INCH XM673 PROJECTILE, M2A2 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ. WALL THICKNESS .40 IN.
CONTACT ANGLE, DEG., DEFLECTION, 10⁻⁴ IN.
450.00
387.50
325.00
262.50
200.00
137.50
75.00
12.50
0
-50.00
0
28.00
56.00
84.00
112.00
140.00
168.00
TRAVEL, IN.
CONTACT ON GUN TUBE
DEFLECTION AT BOURRELET
CONTACT ON SHELL

FIGURE 27c

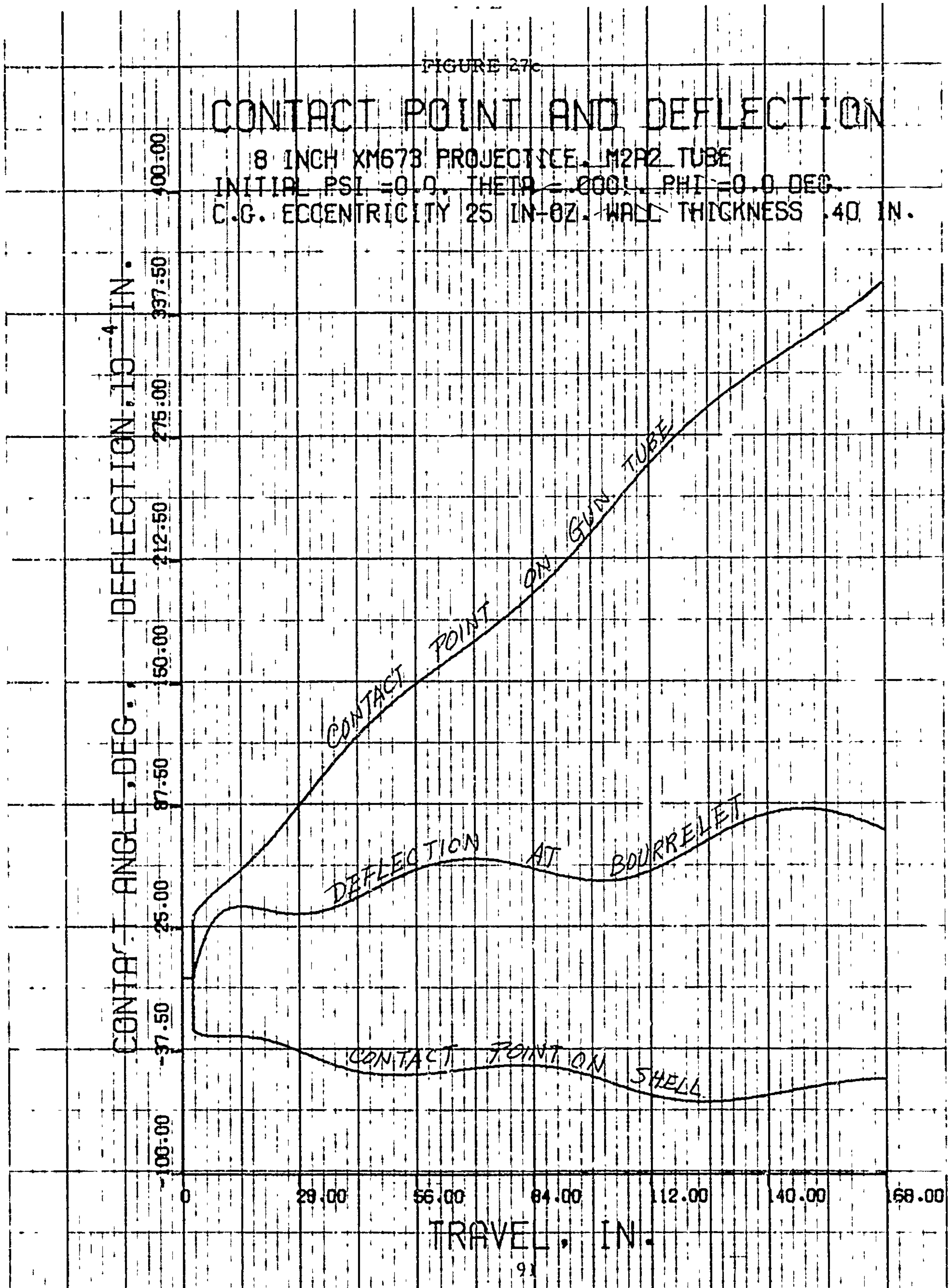

CONTACT POINT AND DEFLECTION
8 INCH XM673 PROJECTILE, M2A2 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ, WALL THICKNESS .40 IN.
CONTACT ANGLE,DEG., DEFLECTION,10^-4 IN.
400.00
337.50
275.00
212.50
150.00
87.50
25.00
-37.50
-100.00
0
28.00
56.00
84.00
112.00
140.00
168.00
TRAVEL, IN.
CONTACT POINT ON GUN TUBE
DEFLECTION AT BOURRELET
CONTACT POINT ON SHELL

FIGURE 27d

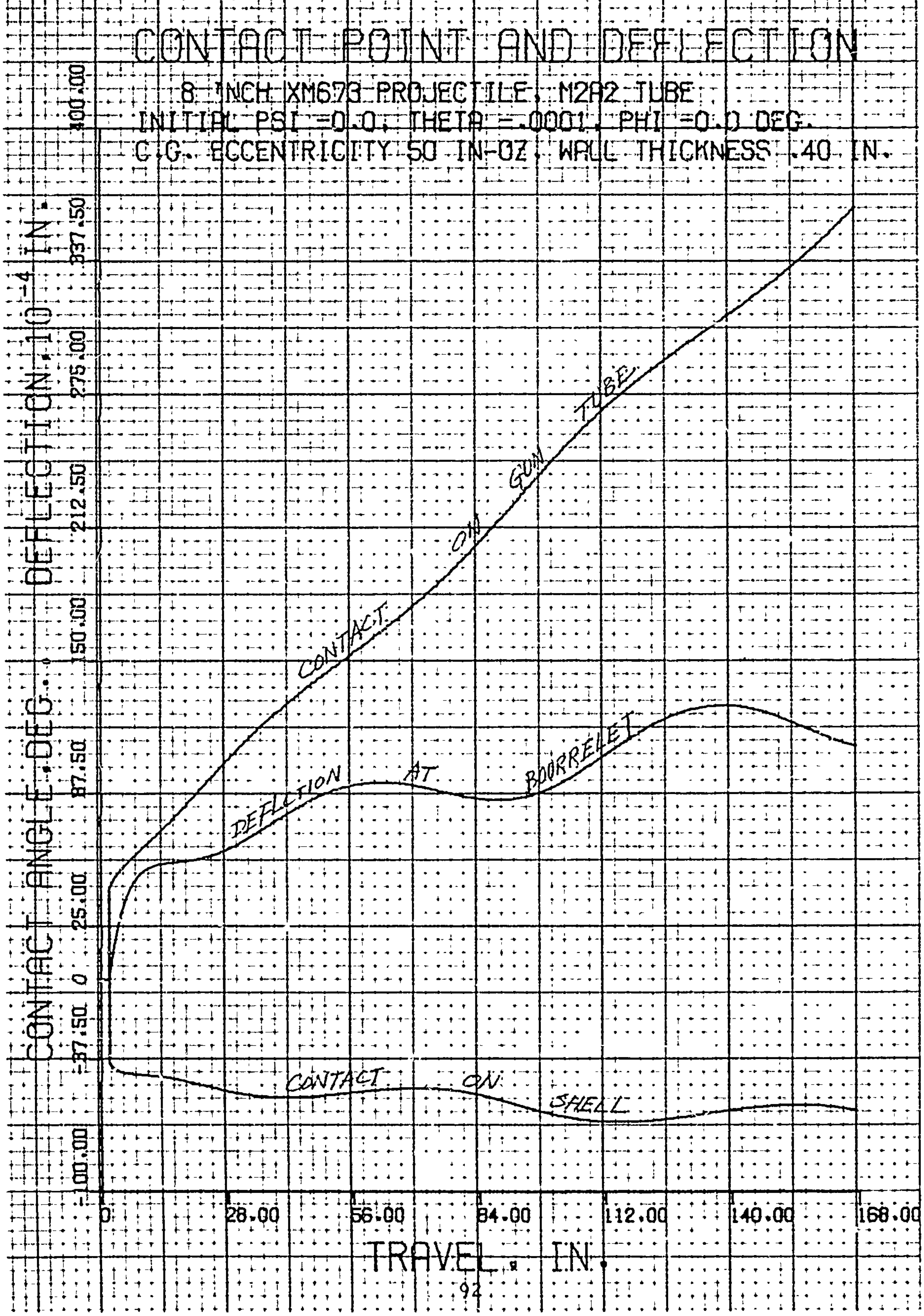

CONTACT POINT AND DEFLECTION
8 INCH XM673 PROJECTILE, M2A2 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ, WALL THICKNESS .40 IN.
CONTACT ANGLE,DEG., DEFLECTION,10 -4 IN.
400.00
337.50
275.00
212.50
150.00
87.50
25.00
0
-37.50
-100.00
0
28.00
56.00
84.00
112.00
140.00
168.00
TRAVEL, IN.
CONTACT ON GUN TUBE
DEFLECTION AT BOURRELET
CONTACT ON SHELL

FIGURE 28a

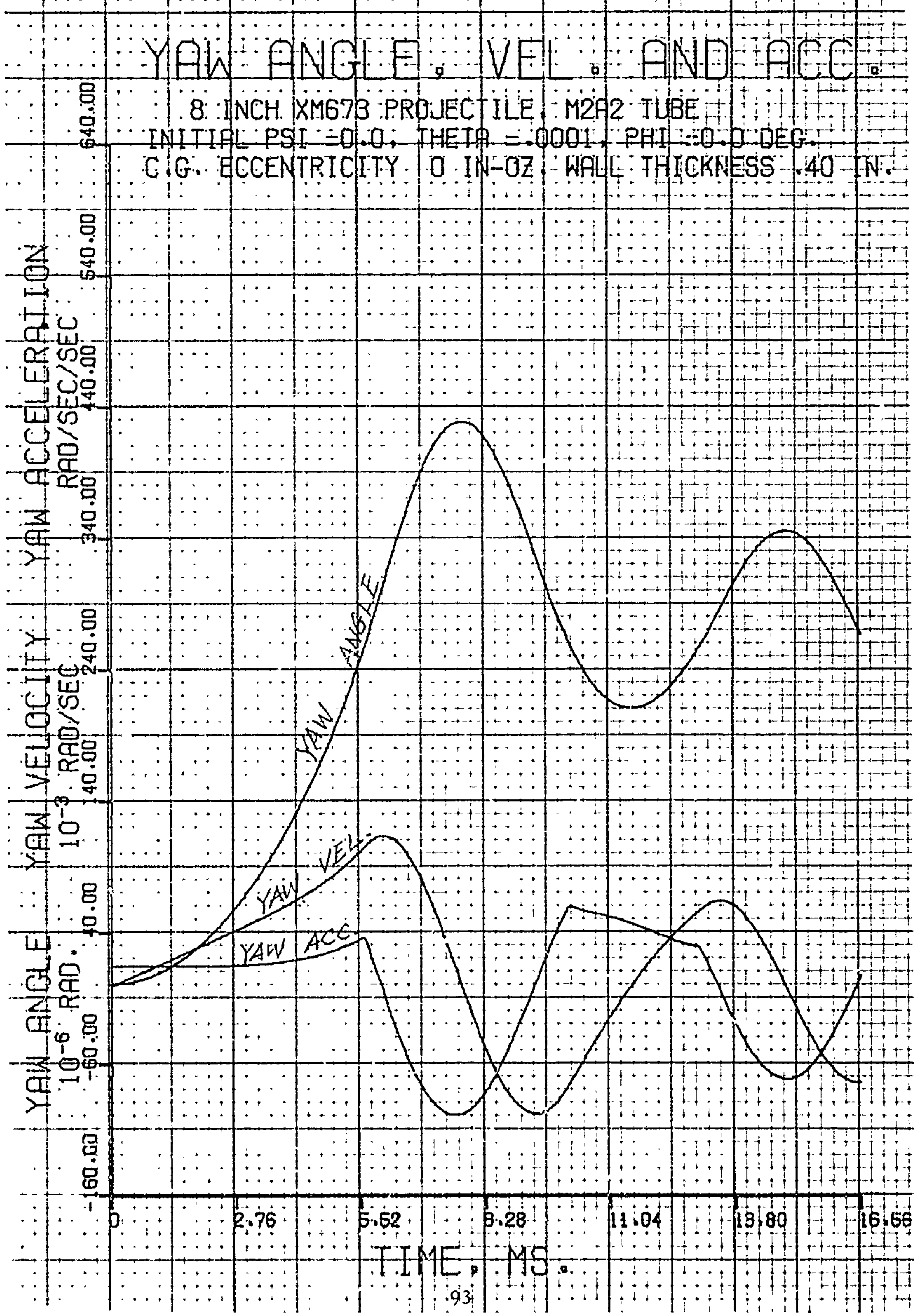

YAW ANGLE, VEL. AND ACC.
8 INCH XM673 PROJECTILE, M2A2 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ, WALL THICKNESS .40 IN.
YAW ACCELERATION RAD/SEC/SEC
YAW VELOCITY 10^{-3} RAD/SEC
YAW ANGLE 10^{-6} RAD.
640.00
540.00
440.00
340.00
240.00
140.00
40.00
-60.00
-160.00
0
2.76
5.52
8.28
11.04
13.80
16.56
TIME, MS.
YAW ANGLE
YAW VEL.
YAW ACC

FIGURE 28b

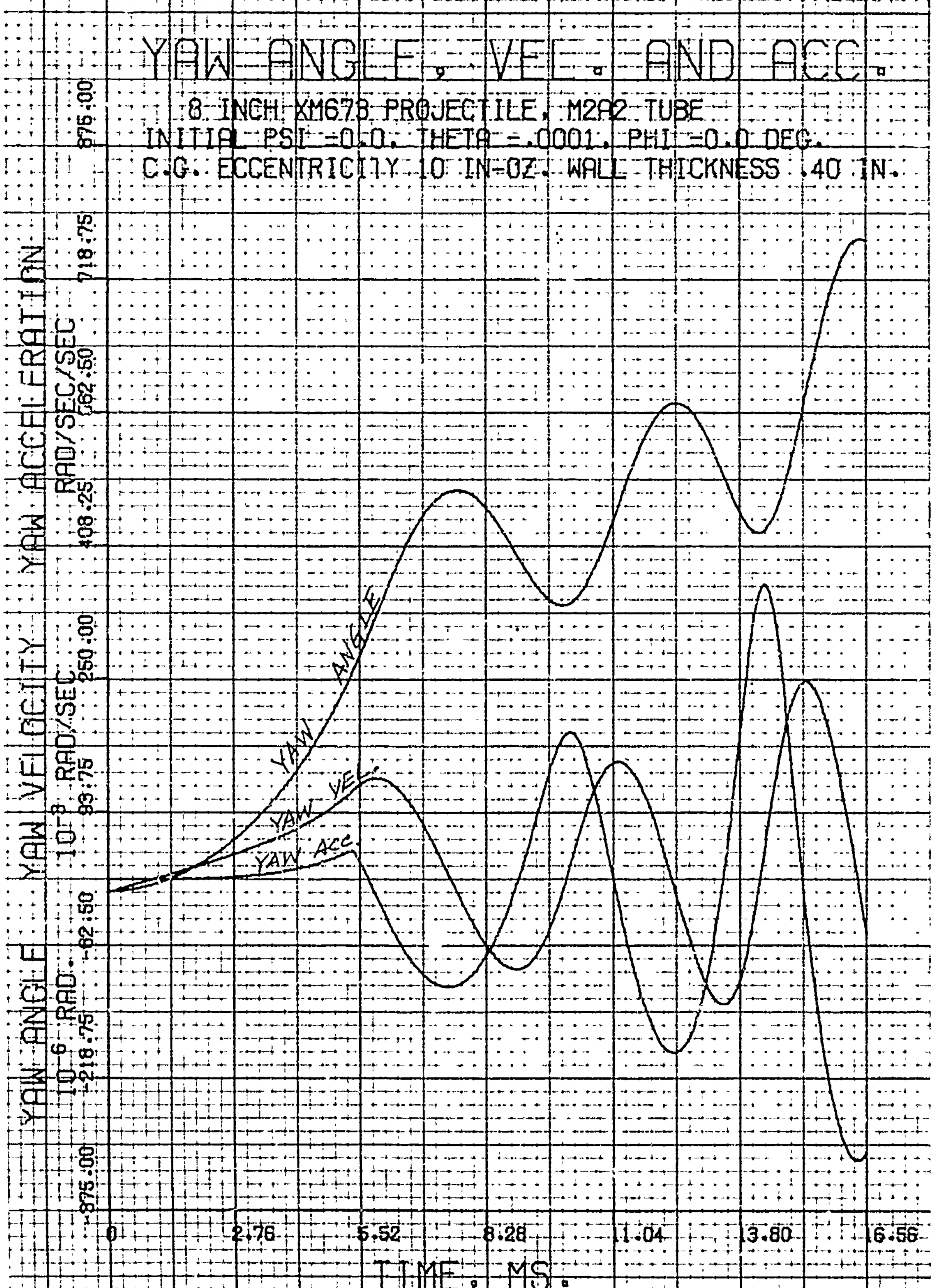

YAW ANGLE, VEL. AND ACC.
8 INCH XM678 PROJECTILE, M2A2 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ. WALL THICKNESS .40 IN.
YAW ANGLE 10-6 RAD.
YAW VELOCITY 10-3 RAD/SEC
YAW ACCELERATION RAD/SEC/SEC
875.00
718.75
562.50
408.25
250.00
93.75
-62.50
-218.75
-375.00
0
2.76
5.52
8.28
11.04
13.80
16.56
TIME, MS.
YAW ANGLE
YAW VEL.
YAW ACC.

FIGURE 28c

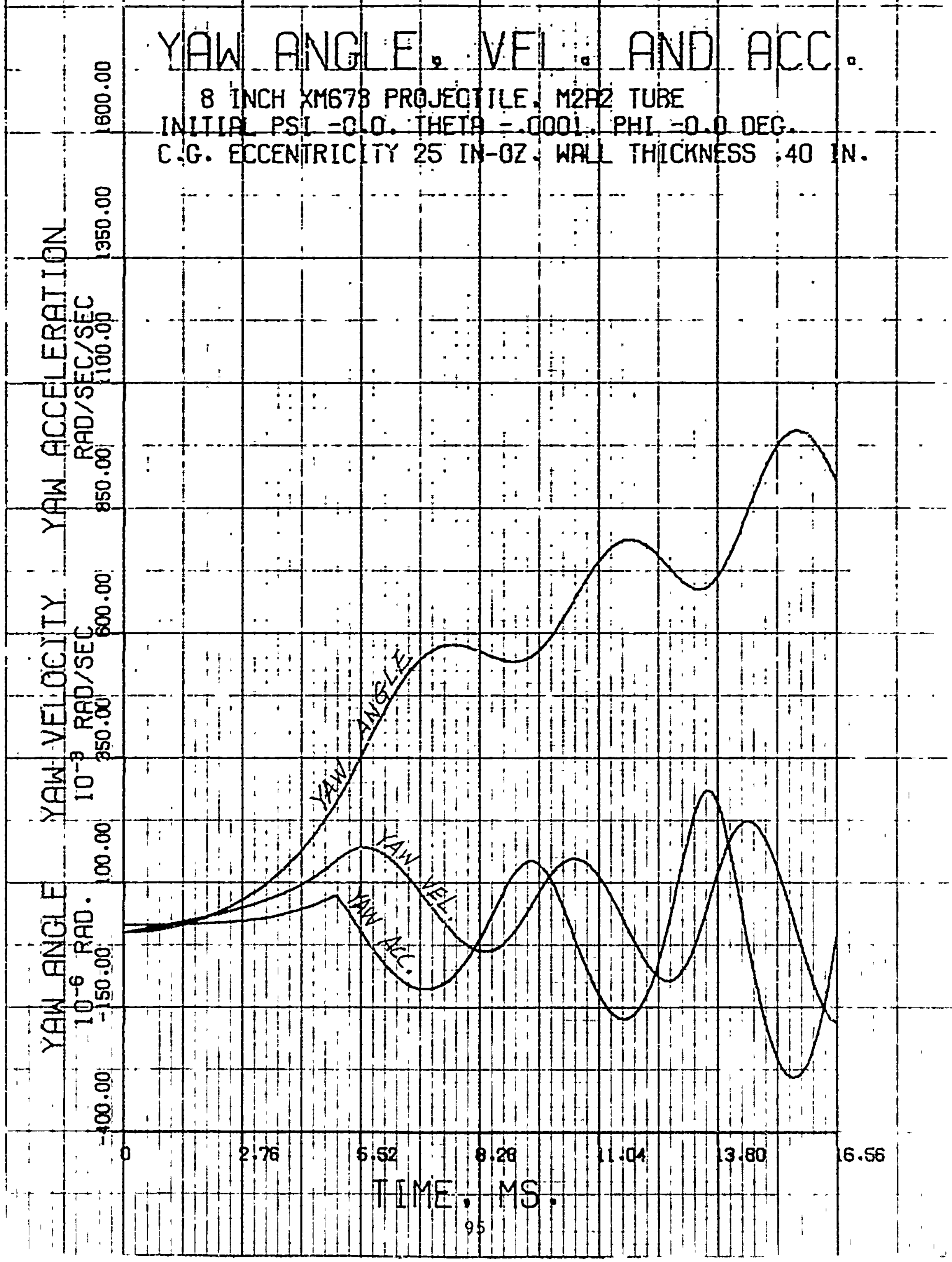

YAW ANGLE, VEL. AND ACC.
8 INCH XM673 PROJECTILE, M2A2 TUBE
INITIAL PSI -0.0, THETA -.0001, PHI -0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ, WALL THICKNESS .40 IN.
YAW ANGLE 10-6 RAD.
YAW VELOCITY 10-3 RAD/SEC
YAW ACCELERATION RAD/SEC/SEC
1600.00
1350.00
1100.00
850.00
600.00
350.00
100.00
-150.00
-400.00
0
2.76
5.52
8.28
11.04
13.80
16.56
TIME, MS.
YAW ANGLE
YAW VEL.
YAW ACC.

FIGURE 28c

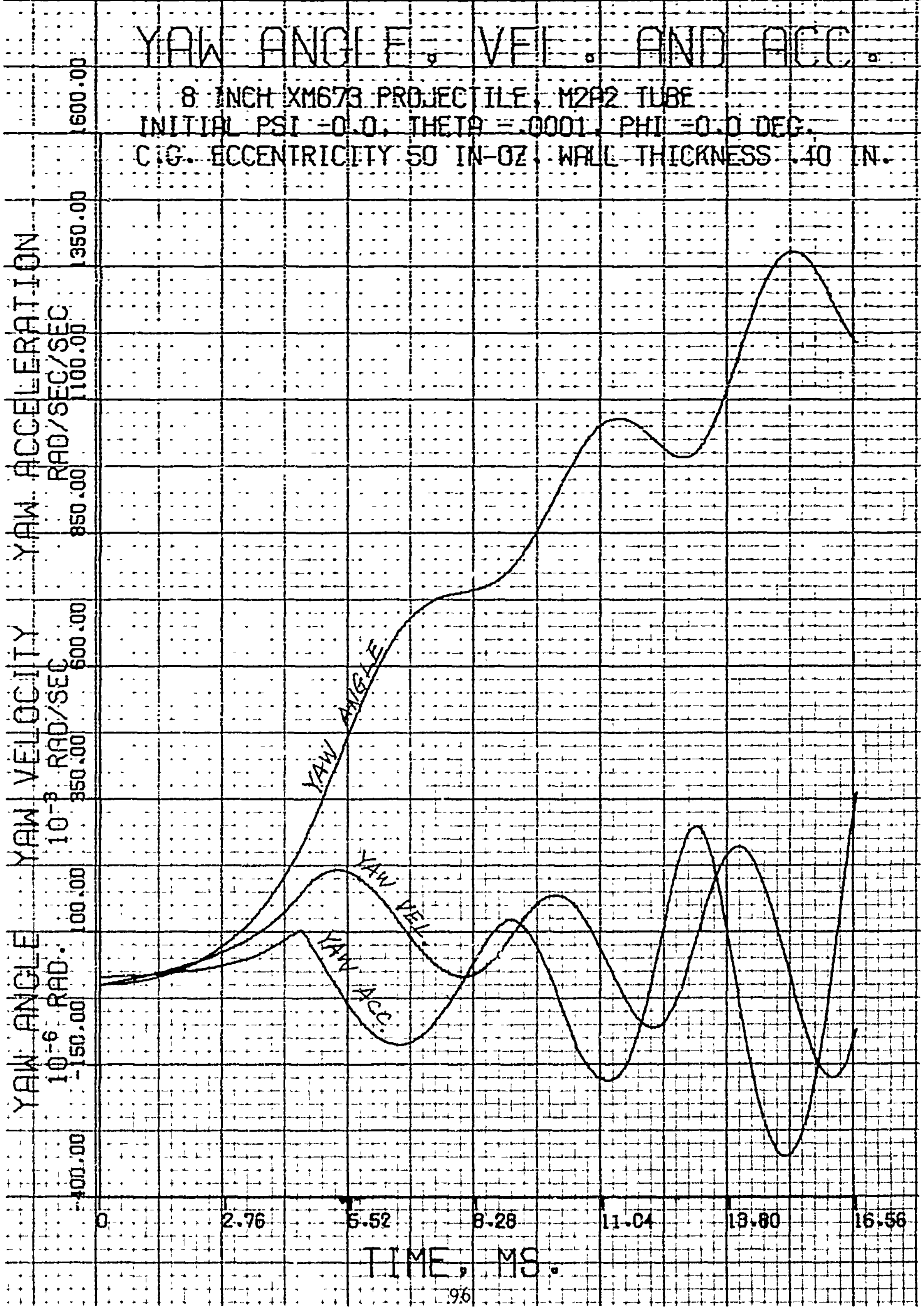
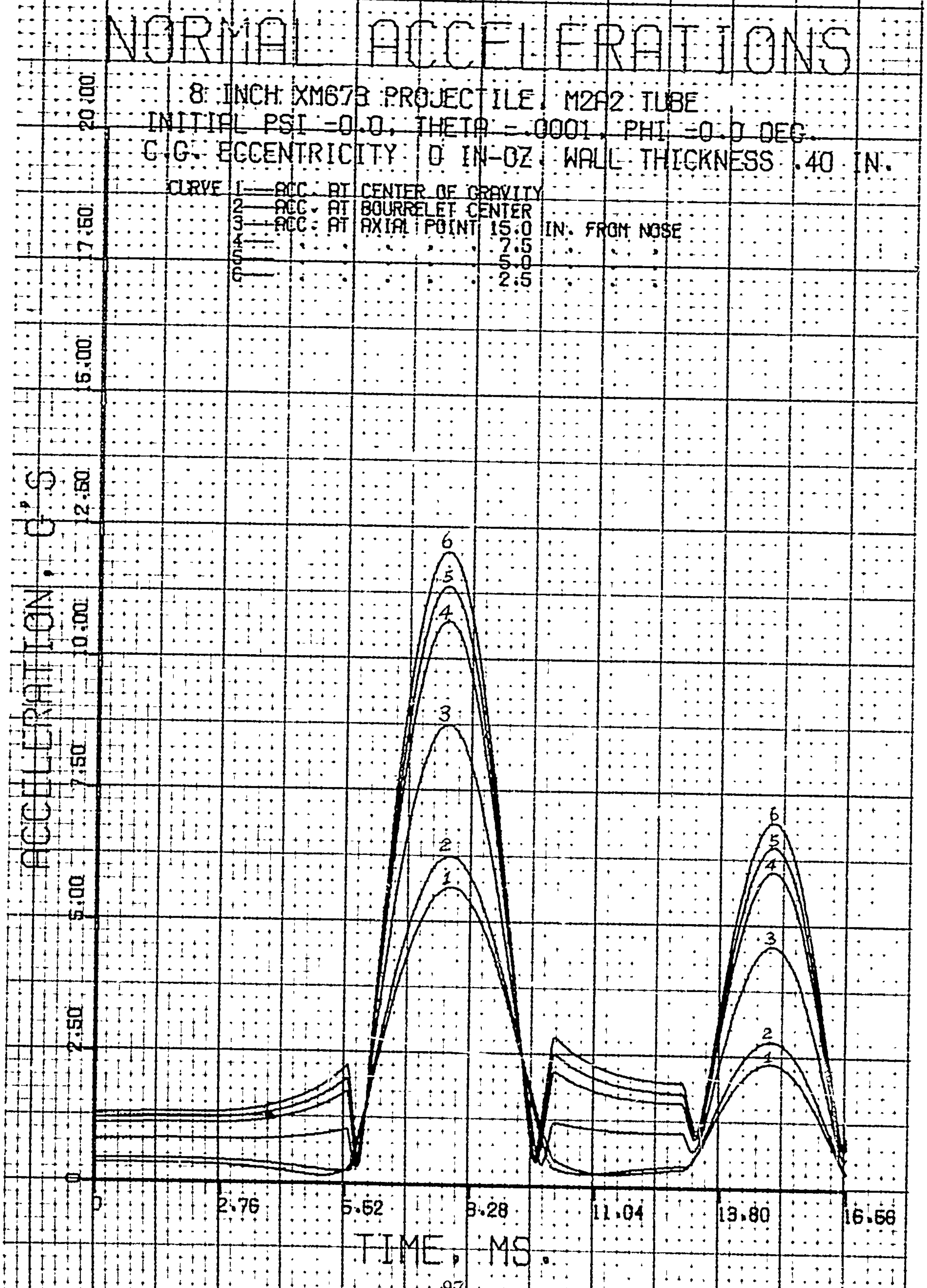

YAW ANGLE, VEL. AND ACC.
8 INCH XM673 PROJECTILE, M2A2 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ, WALL THICKNESS .40 IN.
YAW ACCELERATION RAD/SEC/SEC
YAW VELOCITY 10-3 RAD/SEC
YAW ANGLE 10-6 RAD.
1600.00
1350.00
1100.00
850.00
600.00
350.00
100.00
-150.00
-400.00
YAW ANGLE
YAW VEL.
YAW ACC.
0
2.76
5.52
8.28
11.04
13.80
16.56
TIME, MS.

FIGURE 29a



NORMAL ACCELERATIONS
8 INCH XM673 PROJECTILE, M2A2 TUBE
INITIAL PSI = 0.0, THETA = .0001, PHI = 0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ, WALL THICKNESS .40 IN.
CURVE 1 — ACC. AT CENTER OF GRAVITY
2 — ACC. AT BOURRELET CENTER
3 — ACC. AT AXIAL POINT 15.0 IN. FROM NOSE
4 — 7.5
5 — 5.0
6 — 2.5
ACCELERATION, G'S
20.00
17.50
15.00
12.50
10.00
7.50
5.00
2.50
0
2.76
5.52
8.28
11.04
13.80
16.56
TIME, MS.

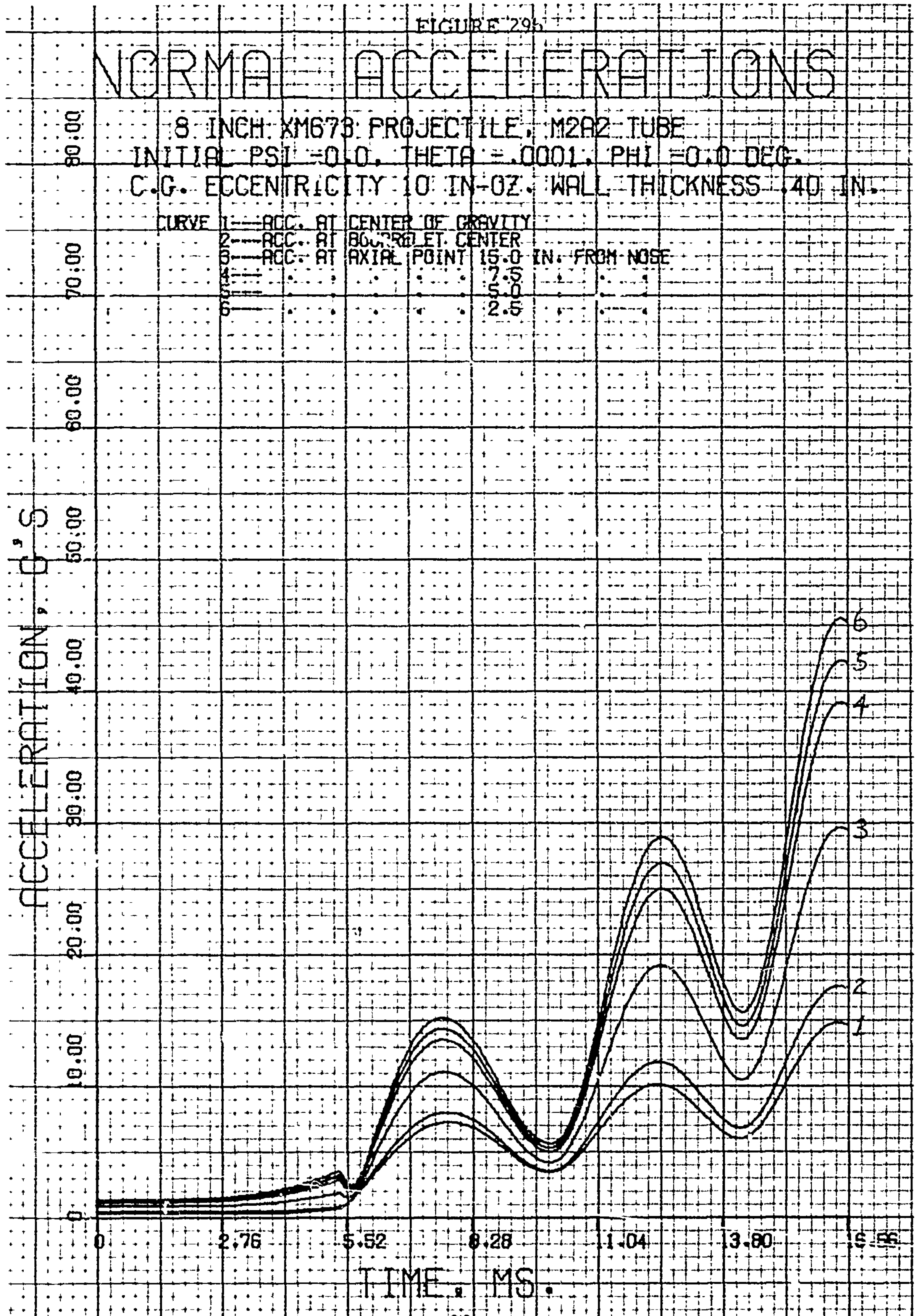


FIGURE 29b
NORMAL ACCELERATIONS
8 INCH XM673 PROJECTILE, M2A2 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ. WALL THICKNESS .40 IN.
CURVE 1---ACC. AT CENTER OF GRAVITY
2---ACC. AT BOURRELET CENTER
3---ACC. AT AXIAL POINT 15.0 IN. FROM NOSE
4--- 7.5
5--- 5.0
6--- 2.5
ACCELERATION, G'S
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0
0
2.76
5.52
8.28
11.04
13.80
16.56
TIME, MS.
1
2
3
4
5
6

FIGURE 29c

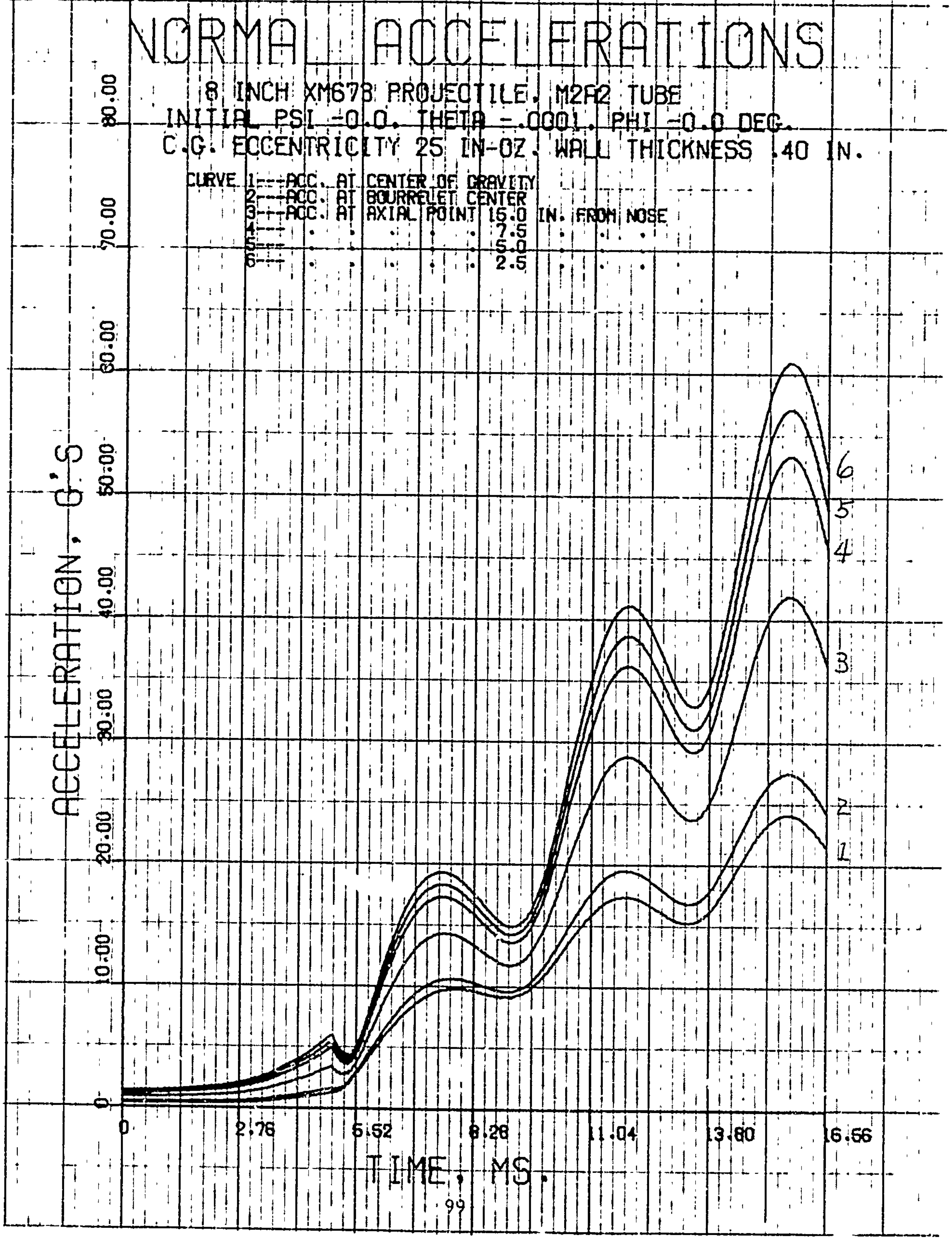
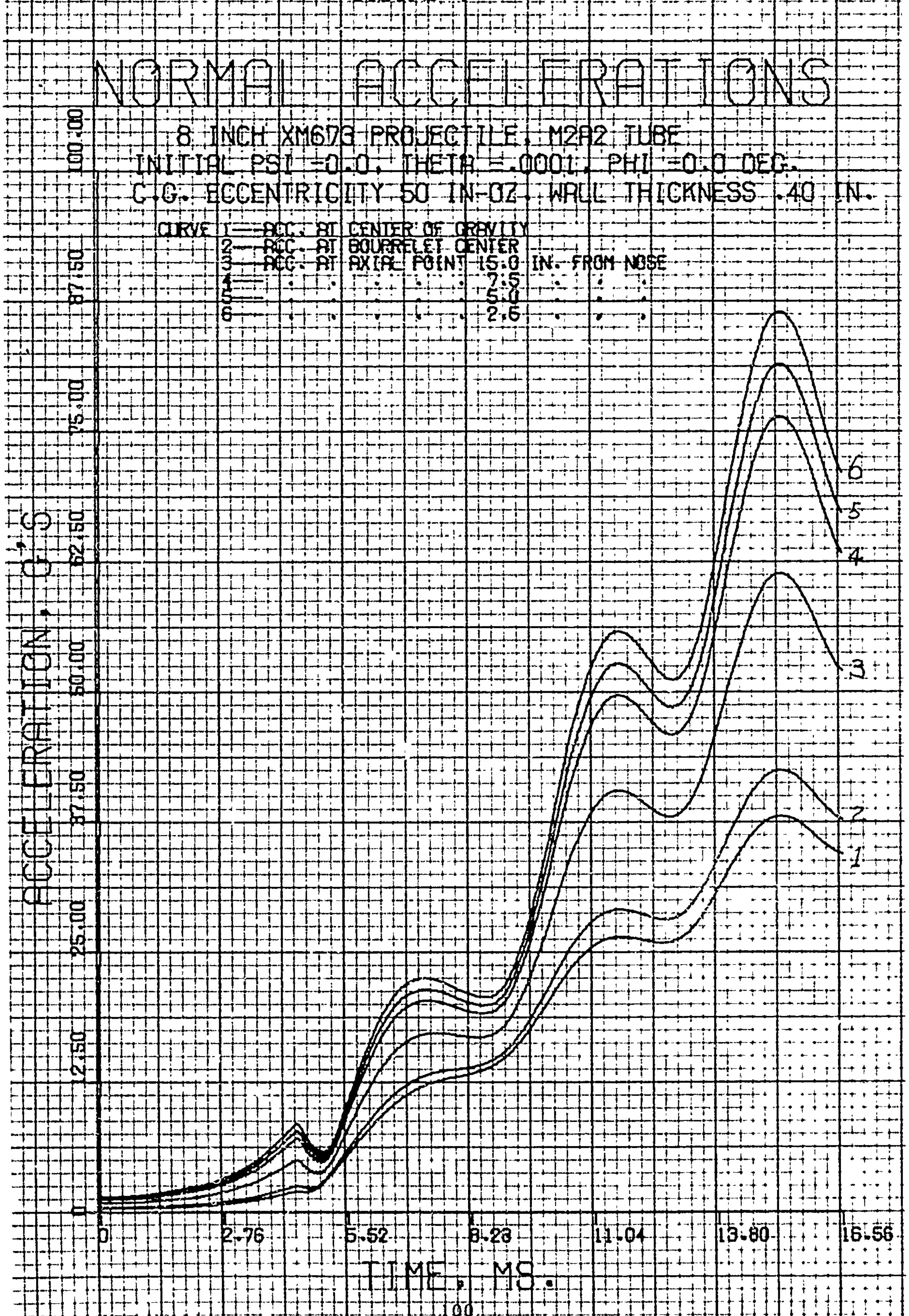

NORMAL ACCELERATIONS
8 INCH XM678 PROJECTILE, M2A2 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .40 IN.
CURVE 1---ACC. AT CENTER OF GRAVITY
2---ACC. AT BOURRELET CENTER
3---ACC. AT AXIAL POINT 15.0 IN. FROM NOSE
4--- " " " " 7.5 " " "
5--- " " " " 5.0 " " "
6--- " " " " 2.5 " " "
ACCELERATION, G'S
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0
0
2.76
5.52
8.28
11.04
13.80
16.56
TIME, MS.
6
5
4
3
2
1

FIGURE 29d



NORMAL ACCELERATIONS
8 INCH XM673 PROJECTILE, M2A2 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ, WALL THICKNESS .40 IN.
CURVE 1—ACC. AT CENTER OF GRAVITY
2—ACC. AT BOURRELET CENTER
3—ACC. AT AXIAL POINT 15.0 IN. FROM NOSE
4— " " " " 7.5 " " "
5— " " " " 5.0 " " "
6— " " " " 2.6 " " "
ACCELERATION, G'S
0
12.50
25.00
37.50
50.00
62.50
75.00
87.50
100.00
TIME, MS.
0
2.76
5.52
8.28
11.04
13.80
16.56
1
2
3
4
5
6

FIGURE 30a

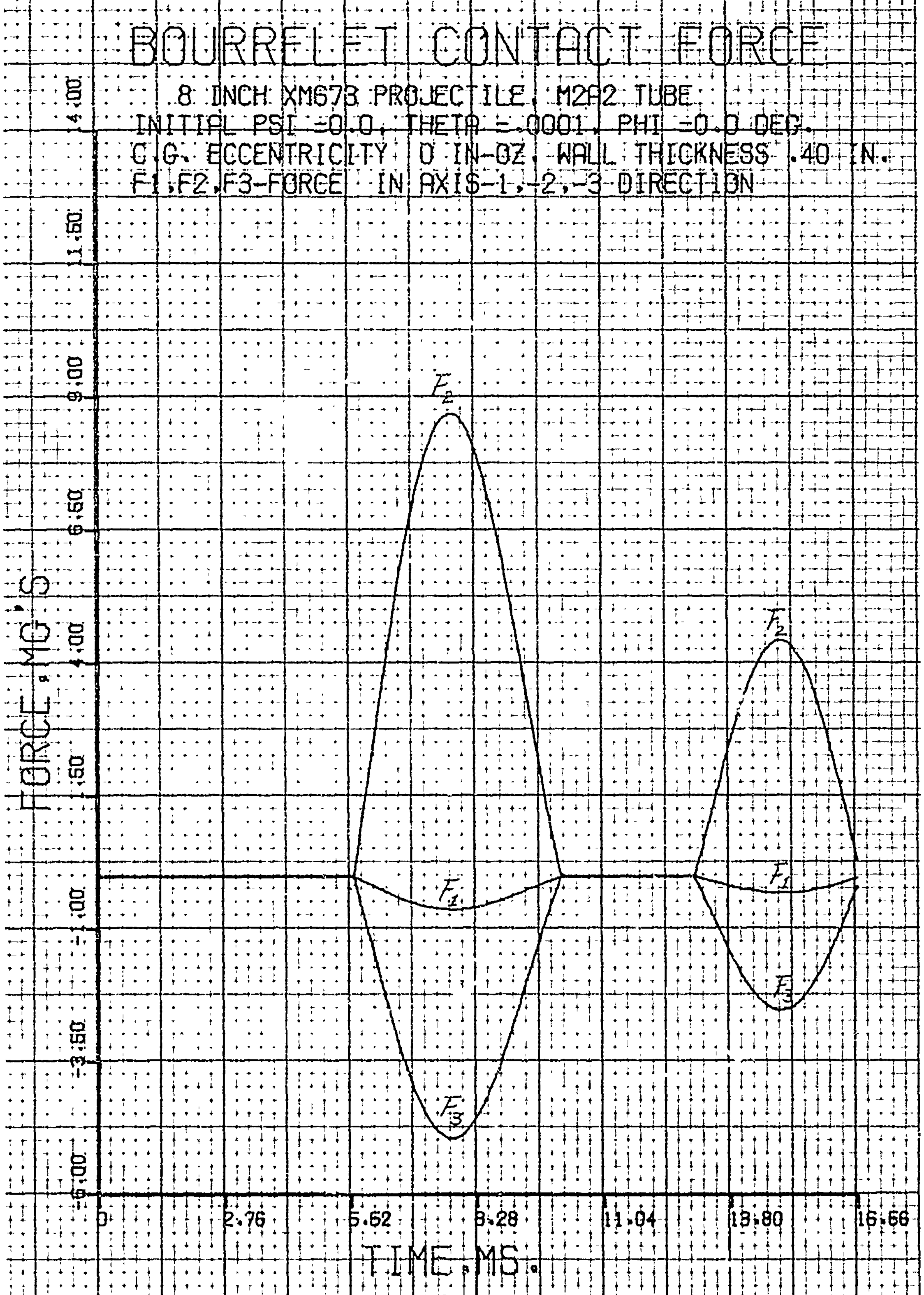
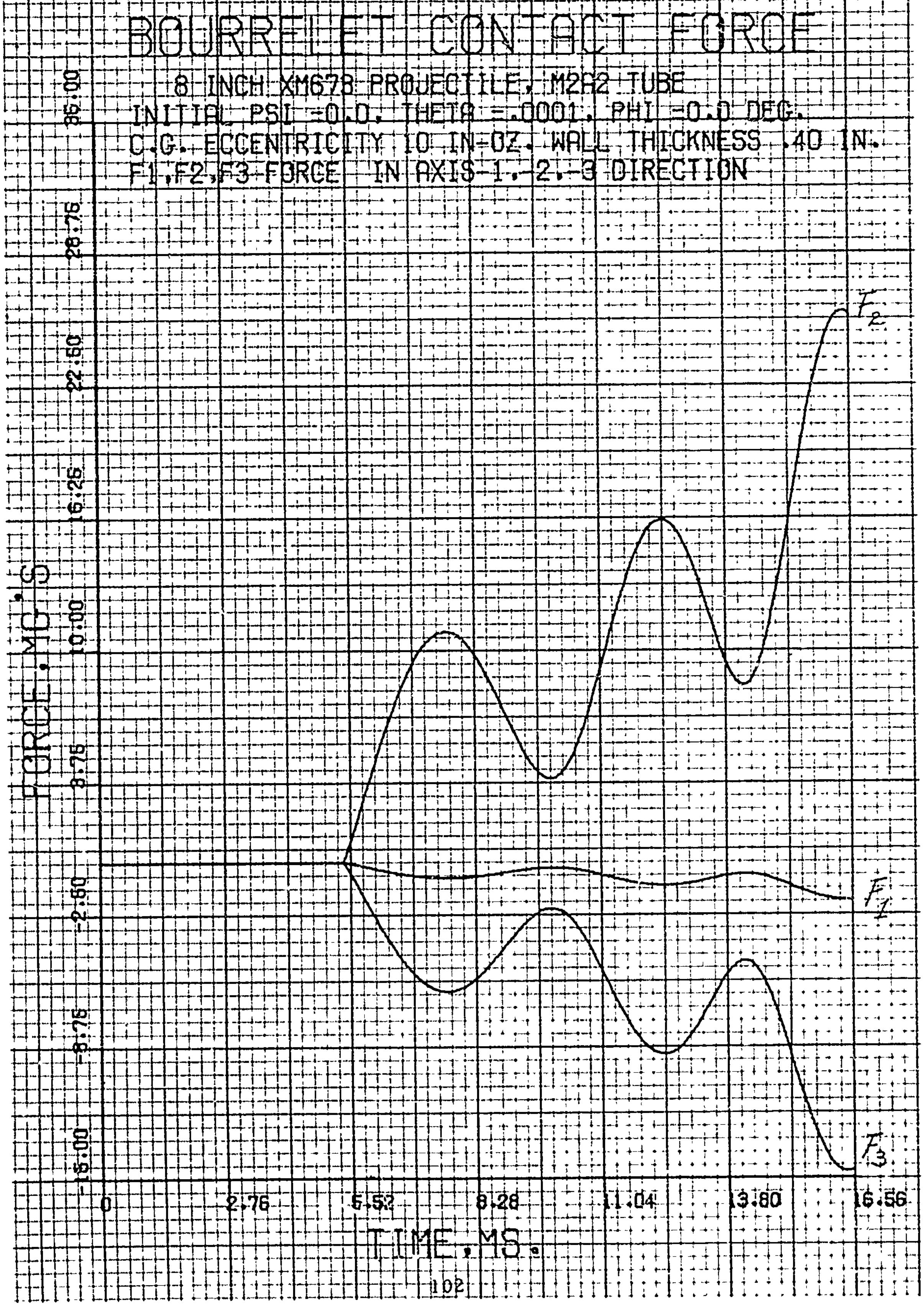

BOURRELET CONTACT FORCE
8 INCH XM673 PROJECTILE, M2A2 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ, WALL THICKNESS .40 IN.
F1,F2,F3-FORCE IN AXIS-1,-2,-3 DIRECTION
FORCE, MG'S
14.00
11.50
9.00
6.50
4.00
1.50
-1.00
-3.50
-6.00
0
2.76
5.52
8.28
11.04
13.80
16.56
TIME, MS.
F_2
F_1
F_3

FIGURE 30b



BOURRELET CONTACT FORCE
8 INCH XM678 PROJECTILE, M2A2 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ. WALL THICKNESS .40 IN.
F1,F2,F3-FORCE IN AXIS-1,-2,-3 DIRECTION
FORCE,MC*G
35.00
28.75
22.50
16.25
10.00
3.75
-2.50
-8.75
-15.00
0
2.76
5.52
8.28
11.04
13.80
16.56
TIME,MS.
F_2
F_1
F_3

FIGURE 30c

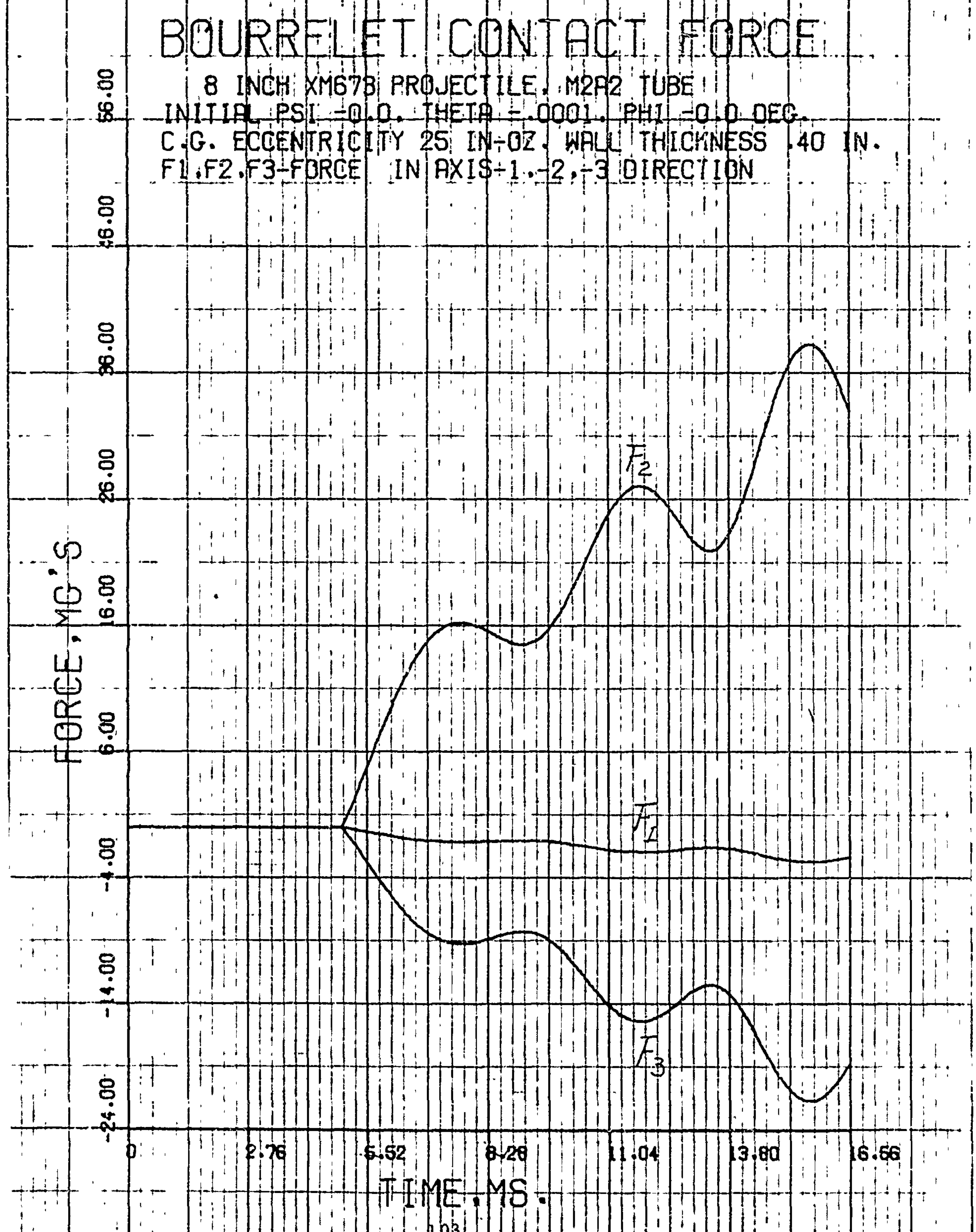
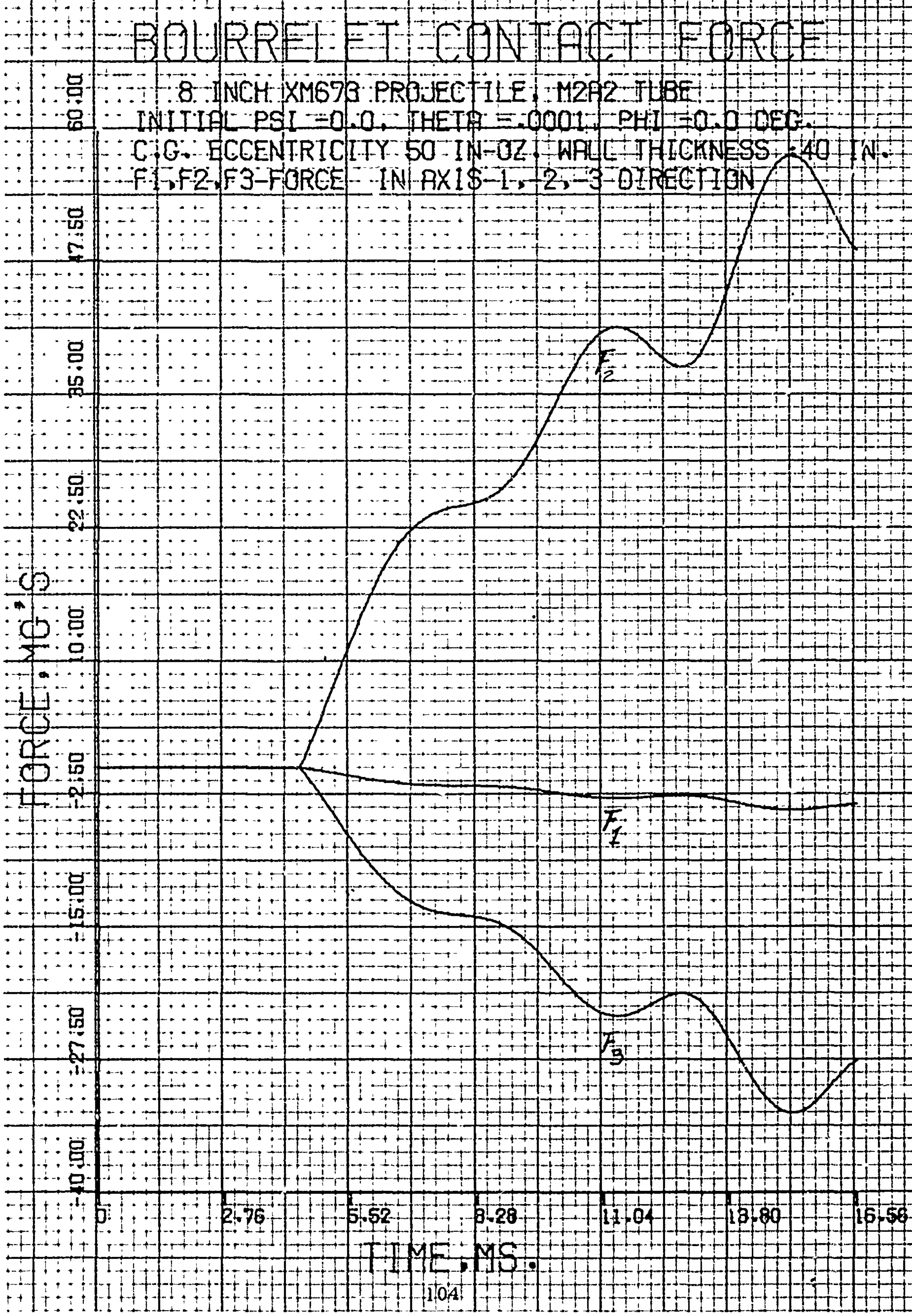

BOURRELET CONTACT FORCE
8 INCH XM678 PROJECTILE, M2A2 TUBE
INITIAL PSI -0.0, THETA -.0001, PHI -0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .40 IN.
F1,F2,F3-FORCE IN AXIS-1,-2,-3 DIRECTION
FORCE, MG'S
56.00
46.00
36.00
26.00
16.00
6.00
-4.00
-14.00
-24.00
F2
F1
F3
0
2.76
5.52
8.28
11.04
13.80
16.56
TIME, MS.

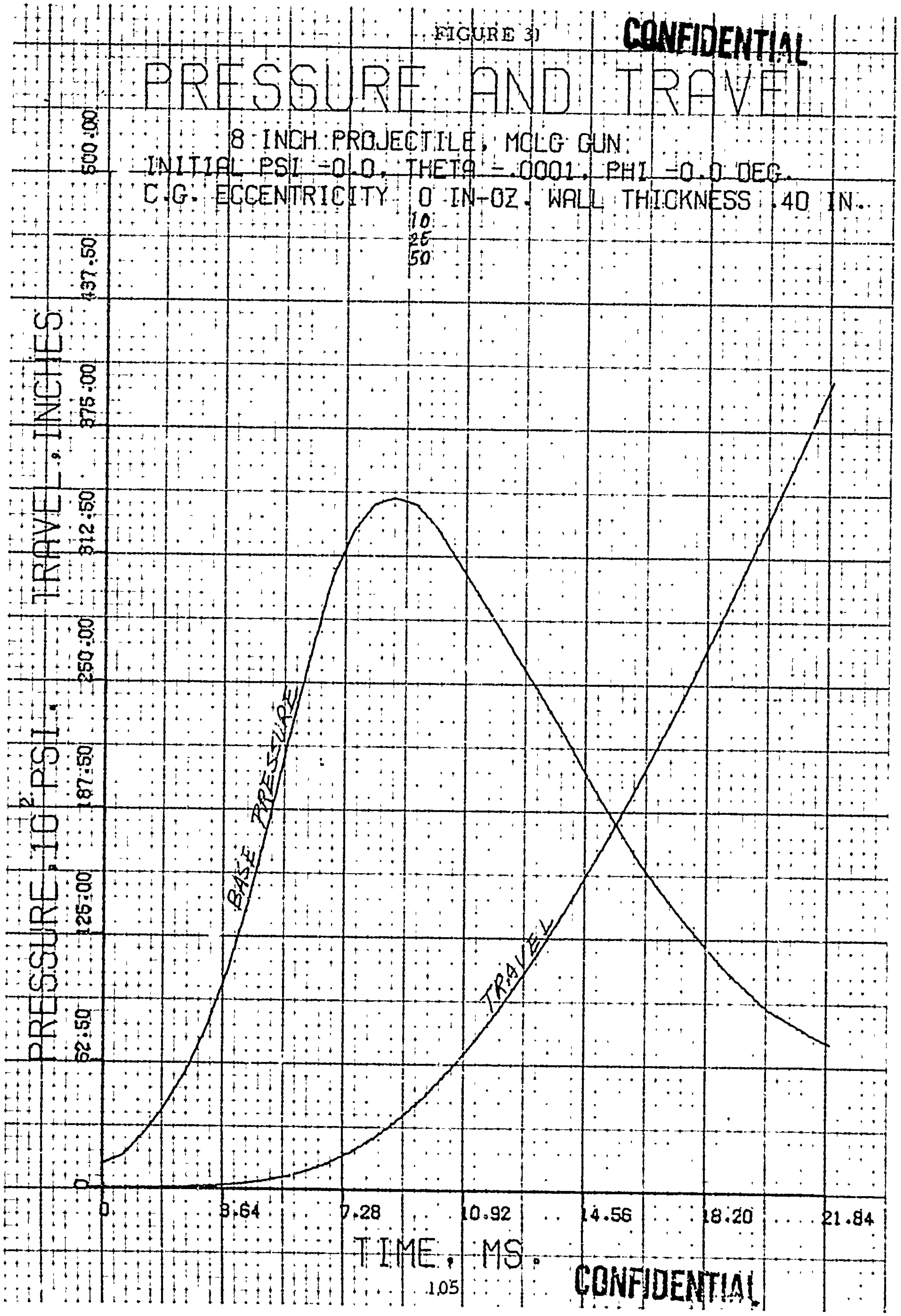
FIGURE 30d


BOURRELET CONTACT FORCE
8 INCH XM673 PROJECTILE, M2A2 TUBE
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ, WALL THICKNESS .40 IN.
F1,F2,F3-FORCE IN AXIS-1,-2,-3 DIRECTION
60.00
47.50
35.00
22.50
10.00
-2.50
-15.00
-27.50
-40.00
FORCE, MG'S
F2
F1
F3
0
2.76
5.52
8.28
11.04
13.80
16.56
TIME, MS.

MCLG GUN

FIGURE 30

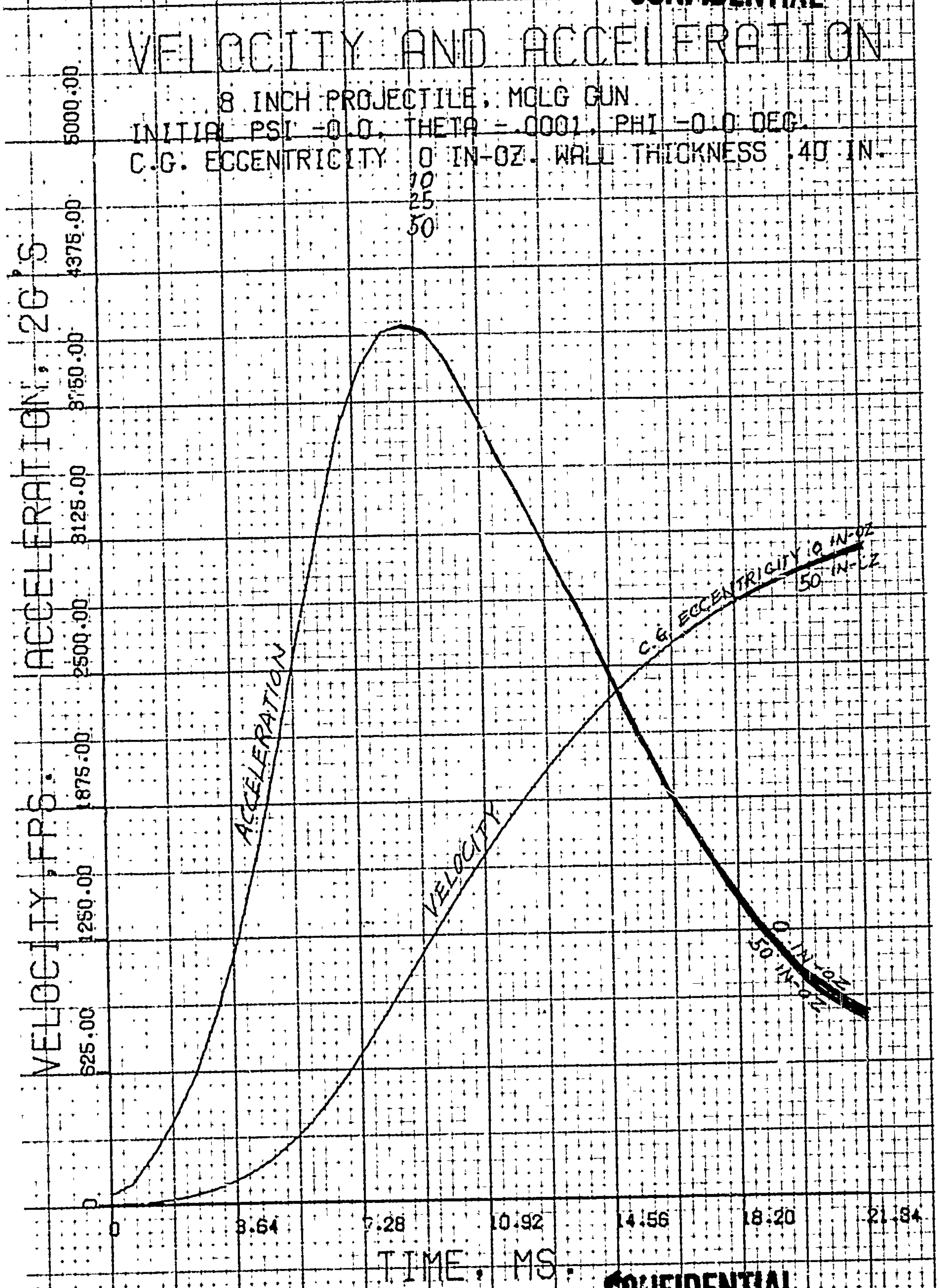
CONFIDENTIAL



CONFIDENTIAL

FIGURE 32

CONFIDENTIAL

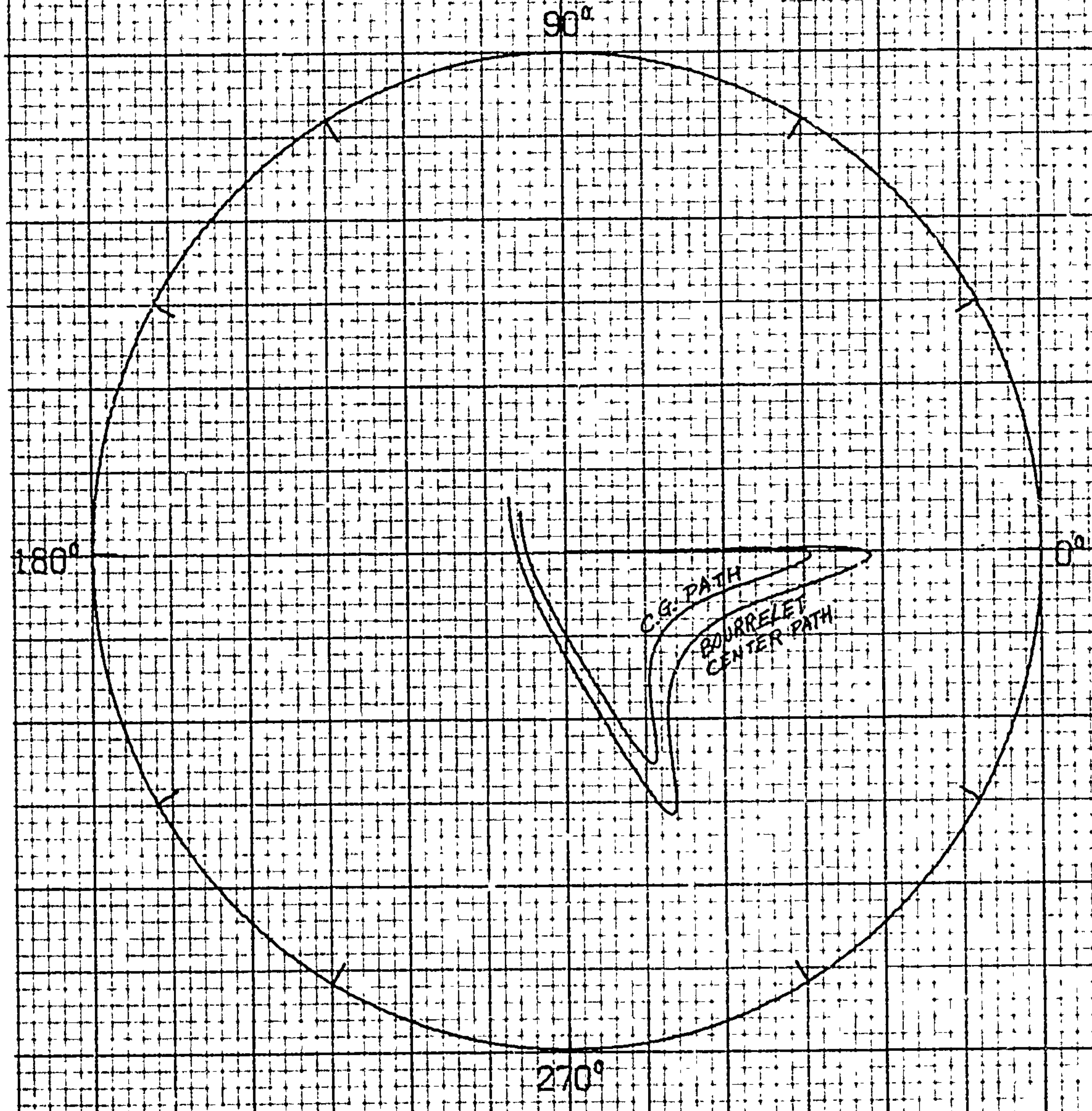


CONFIDENTIAL

FIGURE 33a

C.G. AND BOURRELET CENTER

8 INCH PROJECTILE, MOLG GUN
INITIAL PSI =0.0. THETA =.0001. PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ. WALL THICKNESS .40 IN.

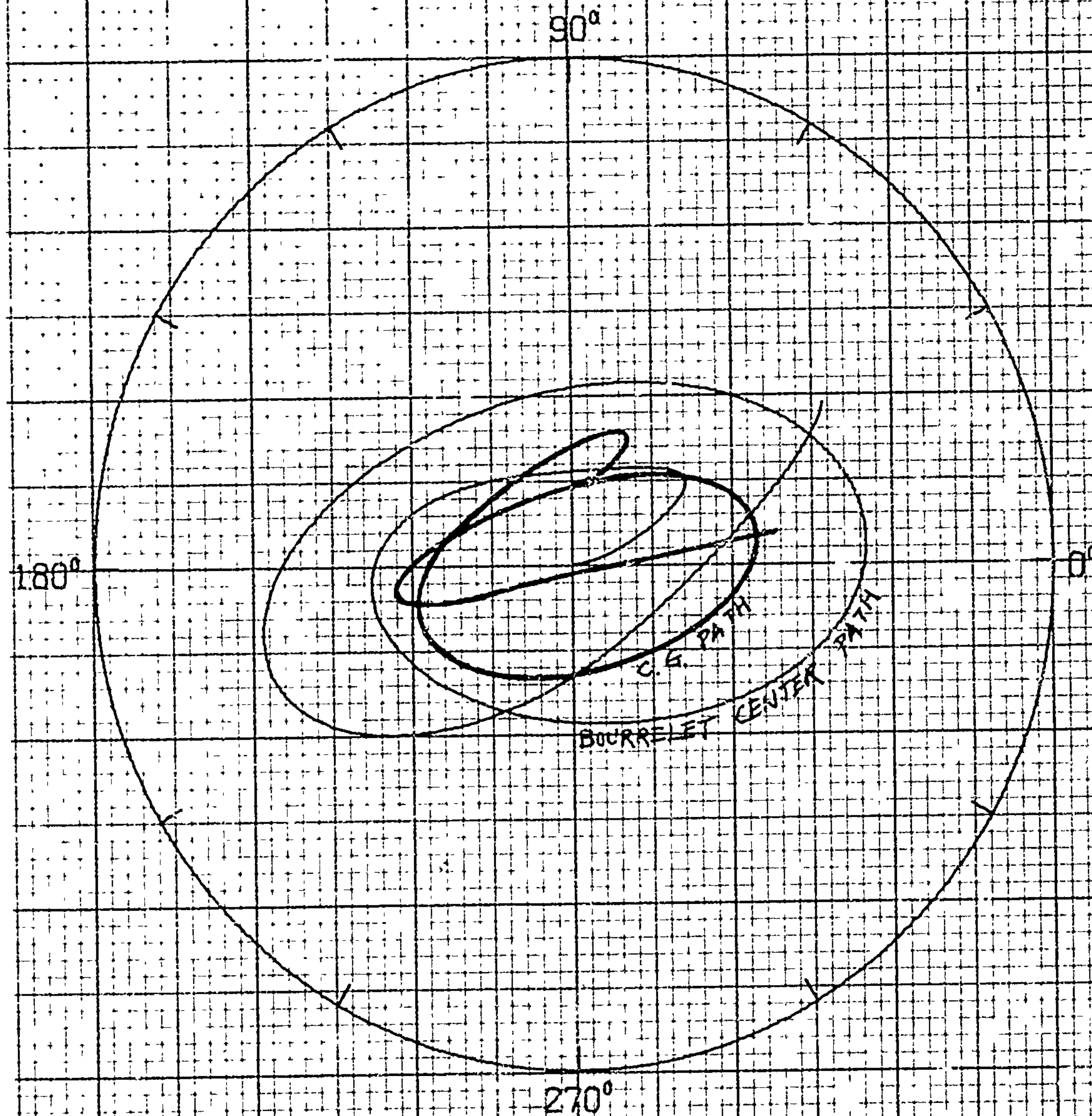


R= .0080 IN.

FIGURE 33b

C.G. AND BOURRELET CENTER

8 INCH PROJECTILE, MOLG GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ, WALL THICKNESS .40 IN.

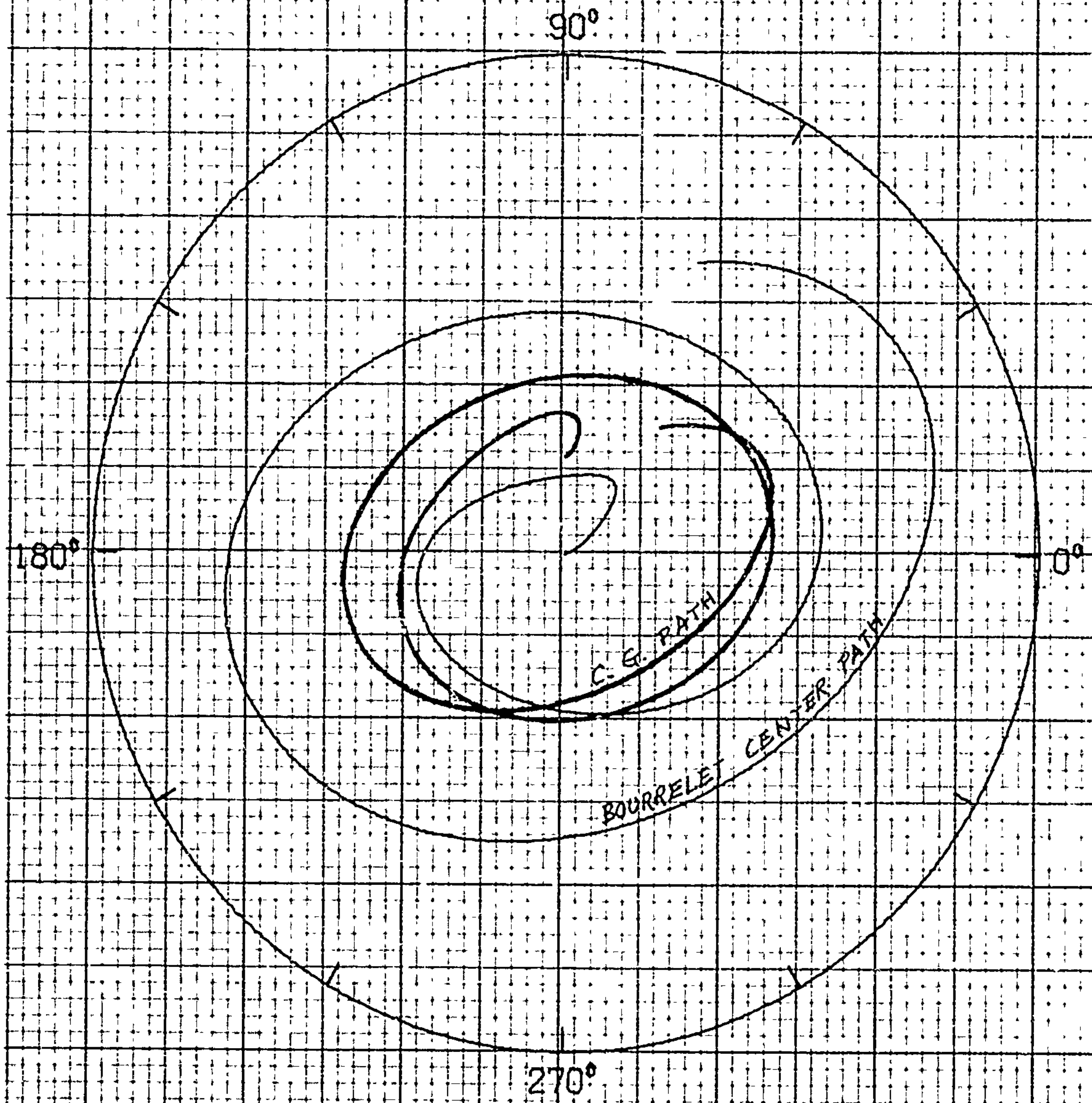


R= .0200 IN.

FIGURE 33c.

C.G. AND BOURRELET CENTER

8 INCH PROJECTILE, MCLG GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .40 IN.



R= .0400 IN.

FIGURE 33d

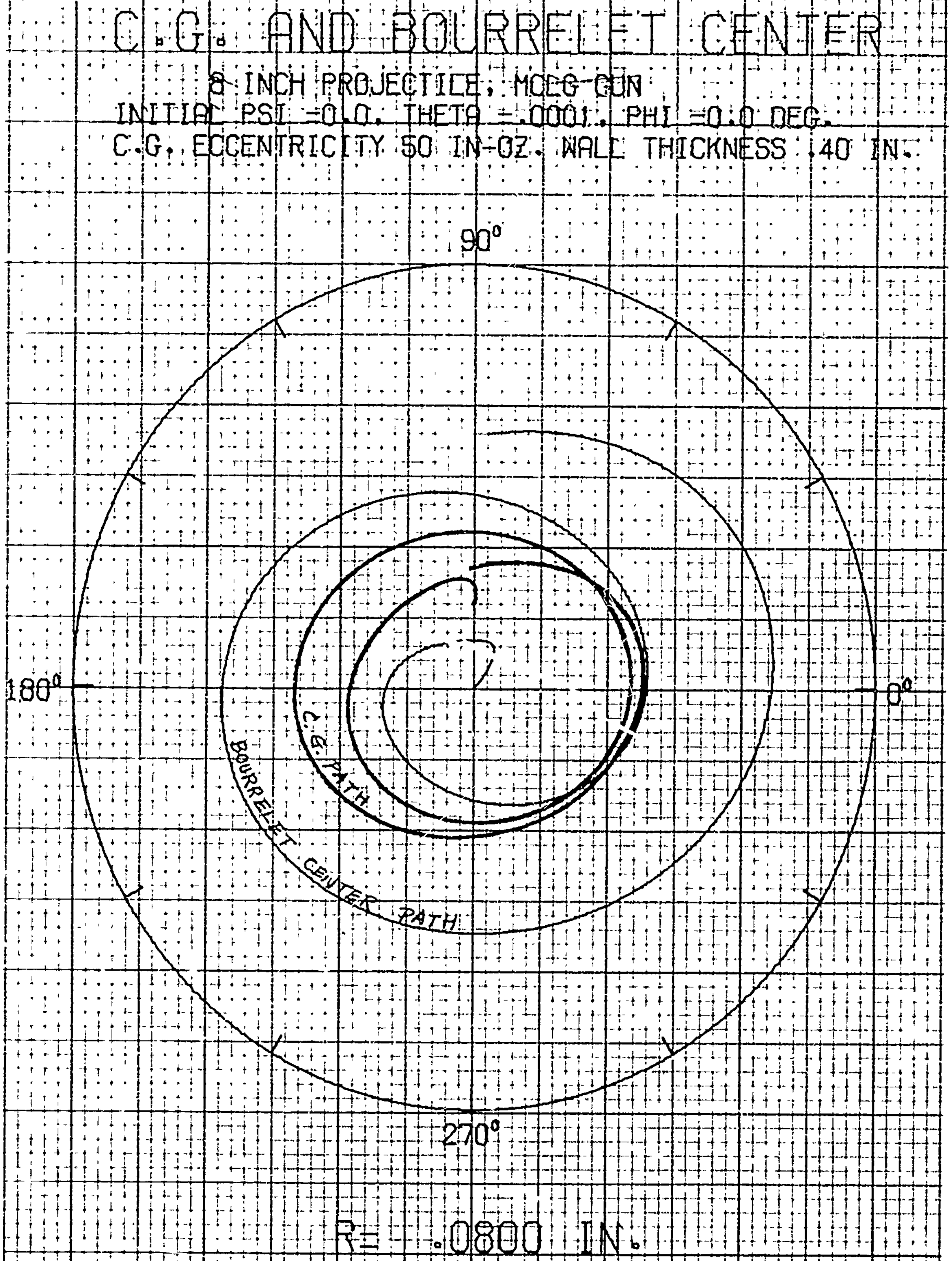

C.G. AND BOURRELET CENTER
8 INCH PROJECTILE, MCLG GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ. WALL THICKNESS .40 IN.
90°
180°
0°
270°
C.G. PATH
BOURRELET CENTER PATH
R= .0800 IN.

FIGURE 34a

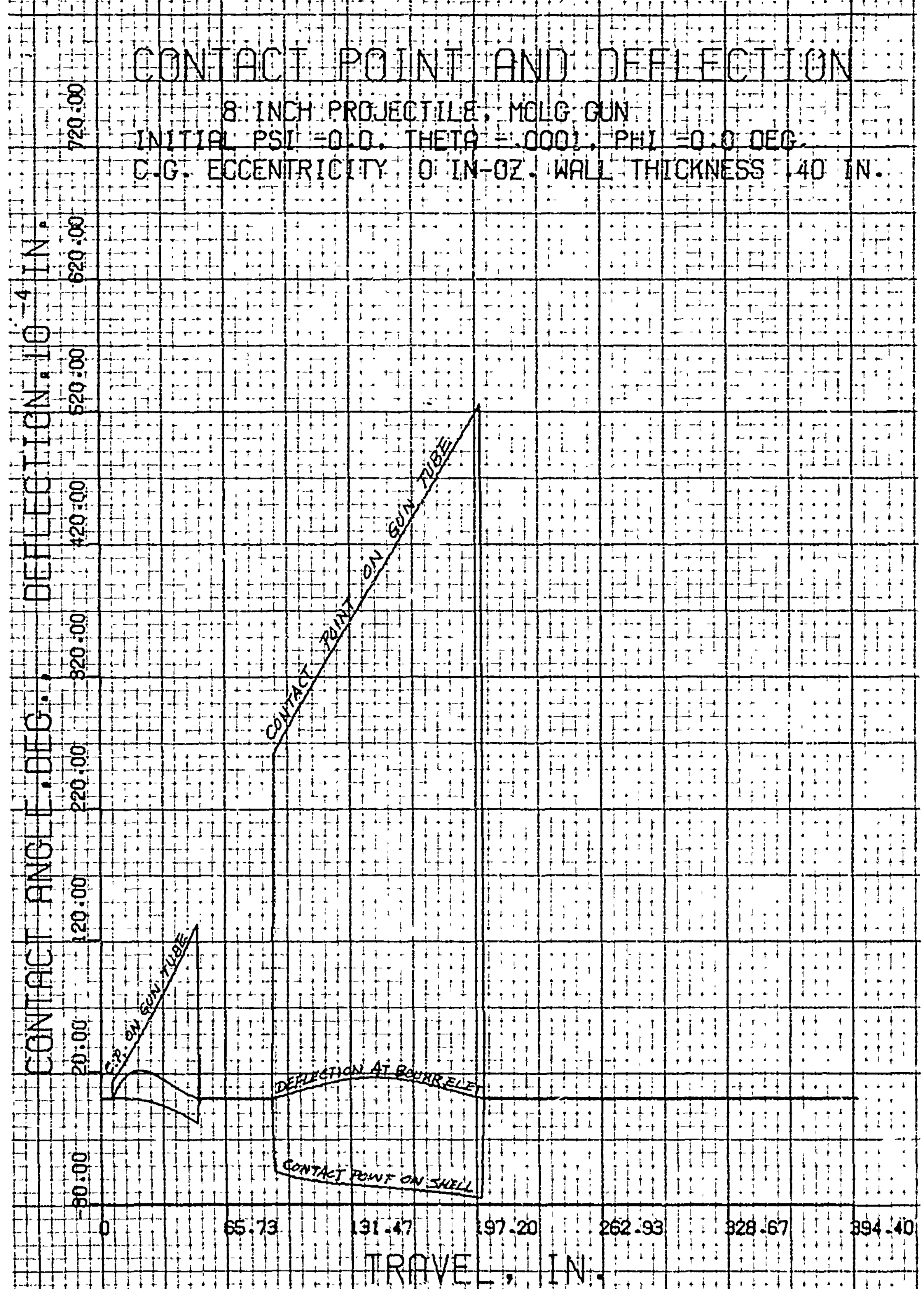
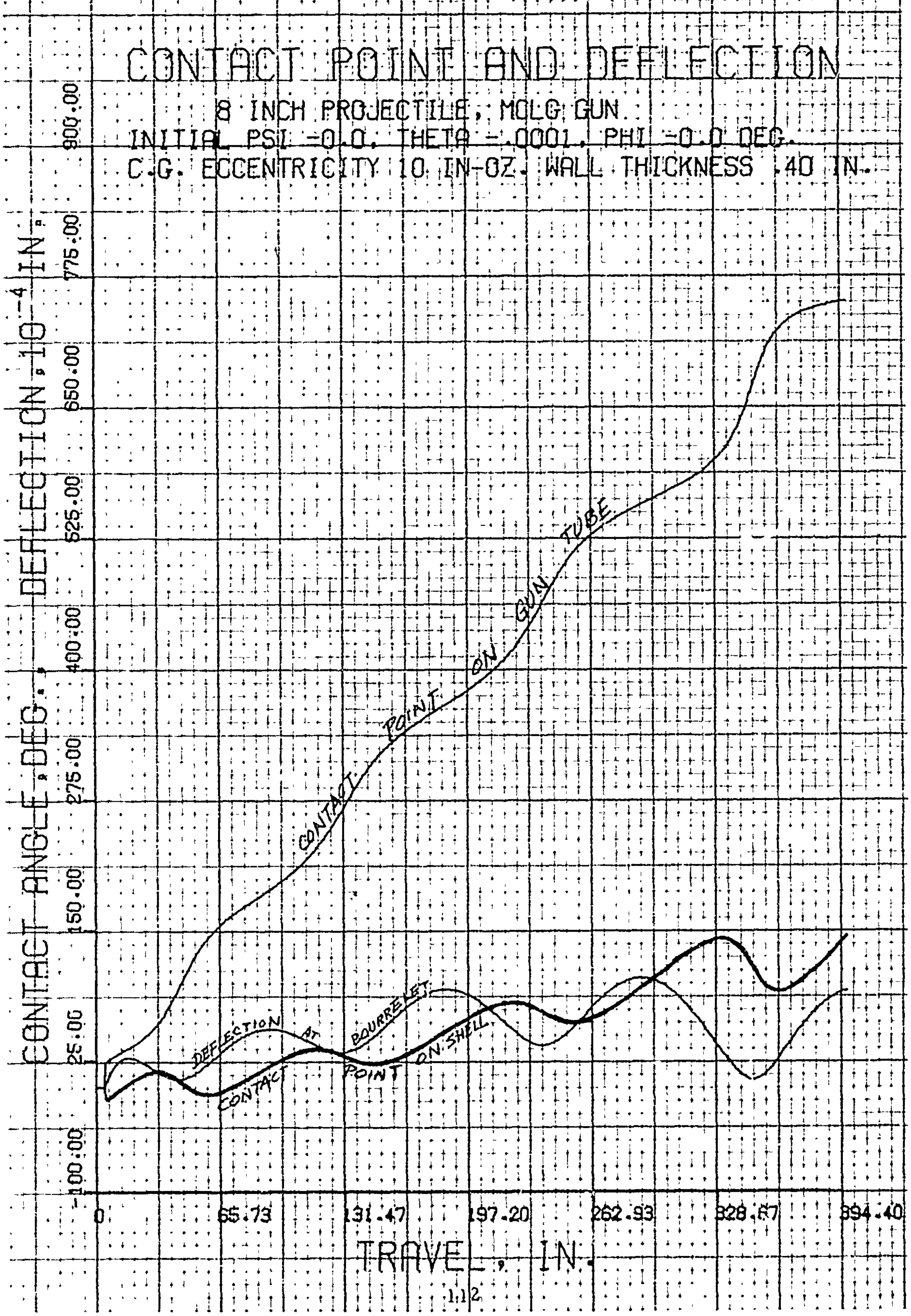

CONTACT POINT AND DEFLECTION
8 INCH PROJECTILE, MOLG GUN
INITIAL PSI =0.0, THETA = .0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ. WALL THICKNESS .40 IN.
CONTACT ANGLE, DEG., DEFLECTION, 10 -4 IN.
720.00
620.00
520.00
420.00
320.00
220.00
120.00
20.00
-80.00
0
65.73
131.47
197.20
262.93
328.67
394.40
TRAVEL, IN.
C.P. ON GUN TUBE
CONTACT POINT ON GUN TUBE
DEFLECTION AT BOURRELET
CONTACT POINT ON SHELL

FIGURE 34b



CONTACT POINT AND DEFLECTION
8 INCH PROJECTILE, MOLG GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ. WALL THICKNESS .40 IN.
CONTACT ANGLE, DEG., DEFLECTION, 10⁻⁴ IN.
900.00
775.00
650.00
525.00
400.00
275.00
150.00
25.00
-100.00
0
65.73
131.47
197.20
262.93
328.67
394.40
TRAVEL, IN.
CONTACT POINT ON GUN TUBE
DEFLECTION AT BOURRELET
CONTACT POINT ON SHELL

FIGURE 34c

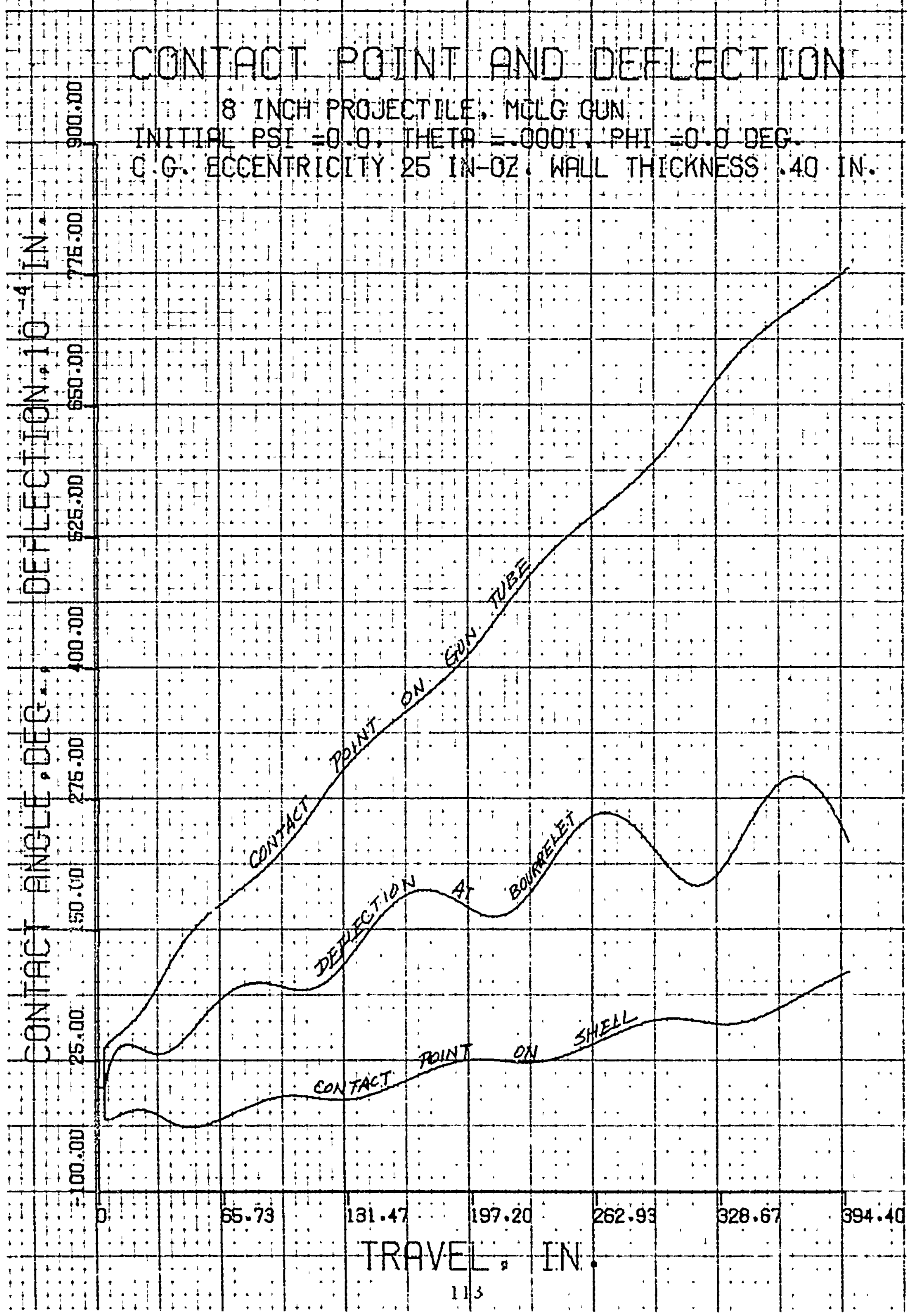
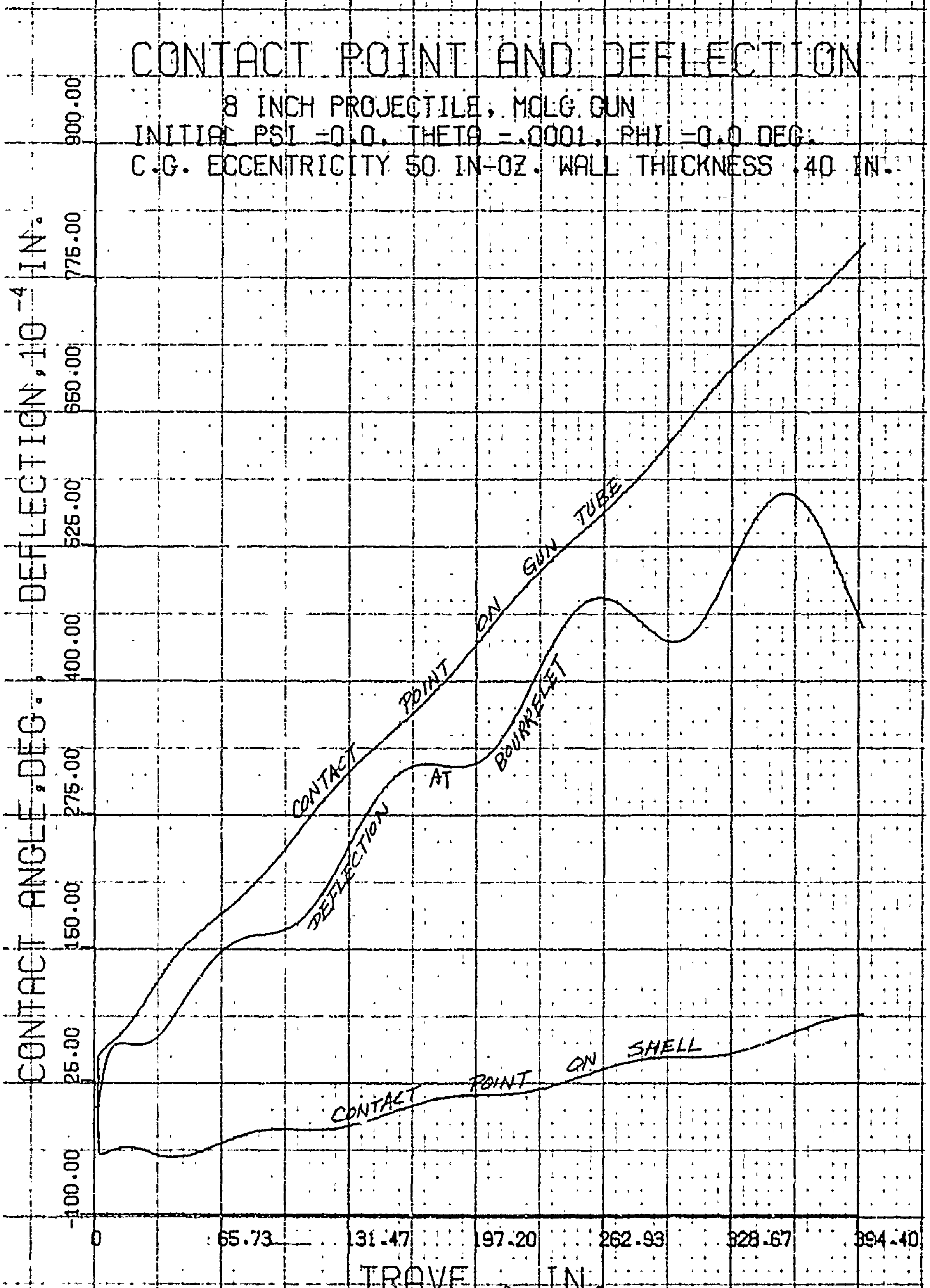

CONTACT POINT AND DEFLECTION
8 INCH PROJECTILE, MCLG GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ, WALL THICKNESS .40 IN.
CONTACT ANGLE,DEG., DEFLECTION,10^-4 IN.
900.00
775.00
650.00
525.00
400.00
275.00
150.00
25.00
-100.00
0
65.73
131.47
197.20
262.93
328.67
394.40
TRAVEL, IN.
CONTACT POINT ON GUN TUBE
DEFLECTION AT BOURRELET
CONTACT POINT ON SHELL

FIGURE 34d


CONTACT POINT AND DEFLECTION
8 INCH PROJECTILE, MOLG GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ. WALL THICKNESS .40 IN.
CONTACT ANGLE,DEG., DEFLECTION,10^-4 IN.
900.00
775.00
650.00
525.00
400.00
275.00
150.00
25.00
-100.00
0
65.73
131.47
197.20
262.93
328.67
394.40
TRAVEL, IN.
CONTACT POINT ON GUN TUBE
DEFLECTION AT BOURRELET
CONTACT POINT ON SHELL

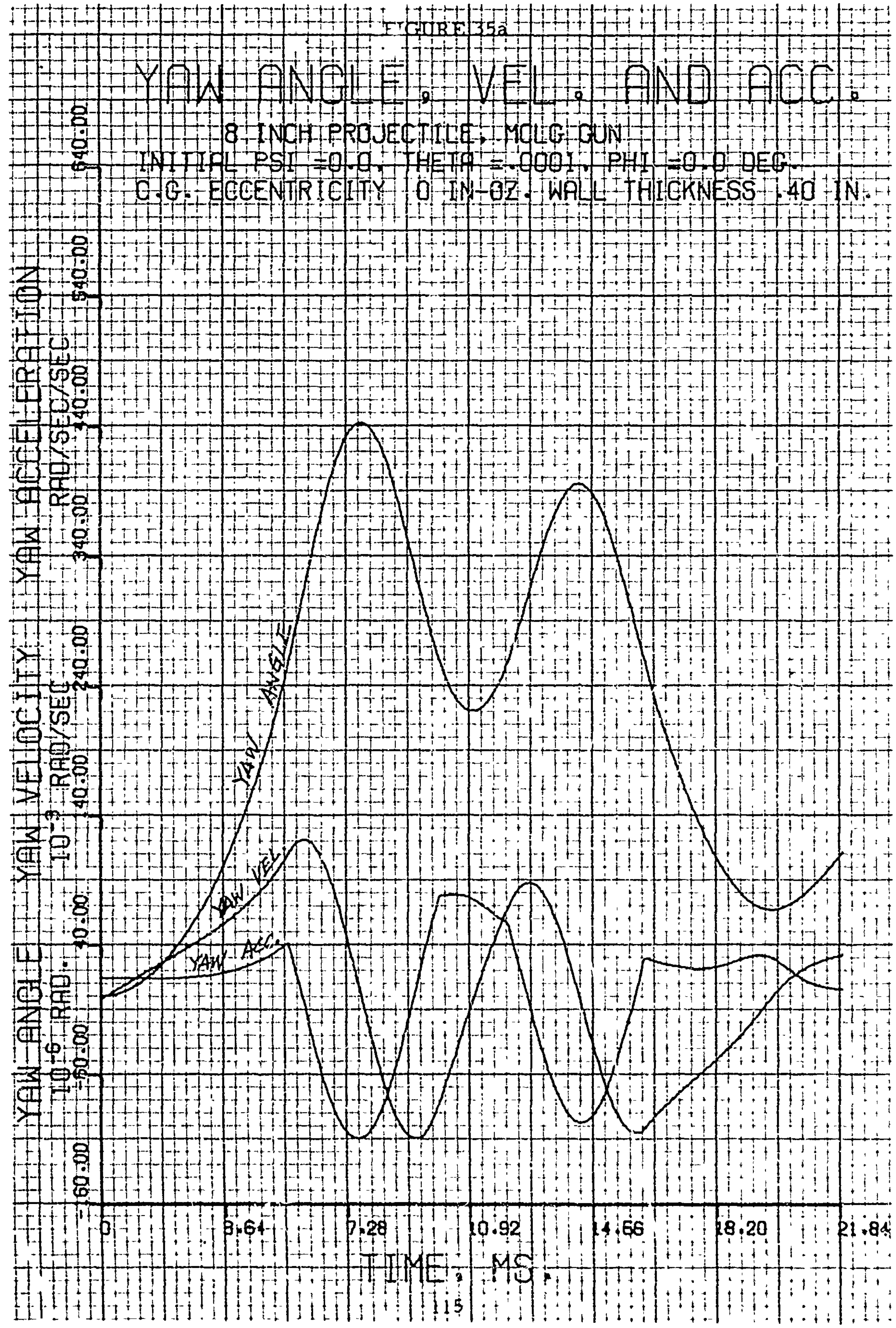


FIGURE 35a
YAW ANGLE, VEL. AND ACC.
8 INCH PROJECTILE, MOLG GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ. WALL THICKNESS .40 IN.
YAW ANGLE YAW VELOCITY YAW ACCELERATION
10-6 RAD. 10-3 RAD/SEC RAD/SEC/SEC
-60.00
-50.00
40.00
140.00
240.00
340.00
340.00
540.00
640.00
0
3.64
7.28
10.92
14.56
18.20
21.84
TIME, MS.
YAW ANGLE
YAW VEL
YAW ACC.

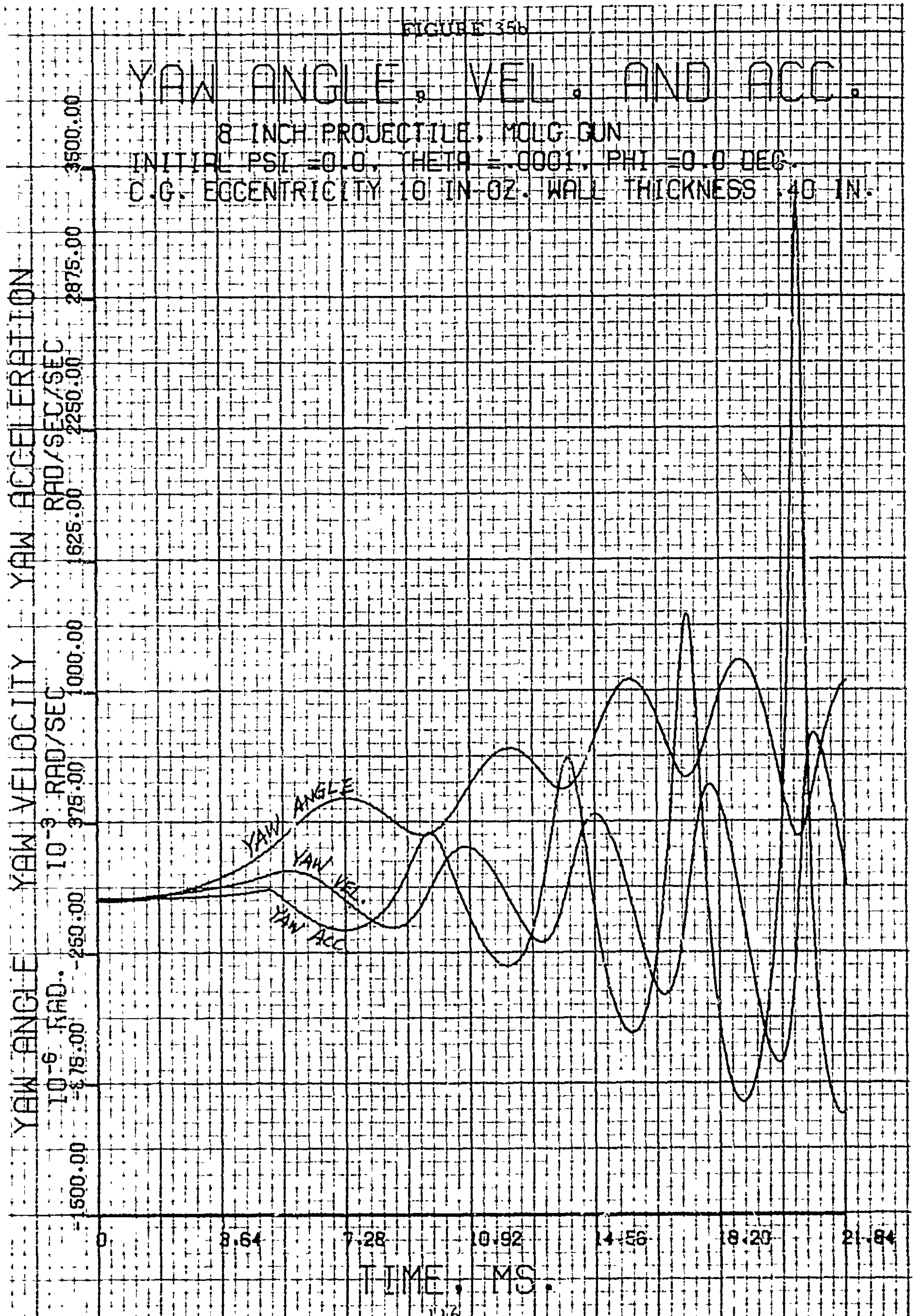


FIGURE 35b
YAW ANGLE, VEL. AND ACC.
8 INCH PROJECTILE, MOLG GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ. WALL THICKNESS .40 IN.
YAW ANGLE
YAW VEL.
YAW ACC
YAW ANGLE YAW VELOCITY YAW ACCELERATION
10-6 RAD. 10-3 RAD/SEC RAD/SEC/SEC
-500.00 -375.00 -250.00 375.00 1000.00 1625.00 2250.00 2875.00 3500.00
0 3.64 7.28 10.92 14.56 18.20 21.84
TIME, MS.

FIGURE 35c

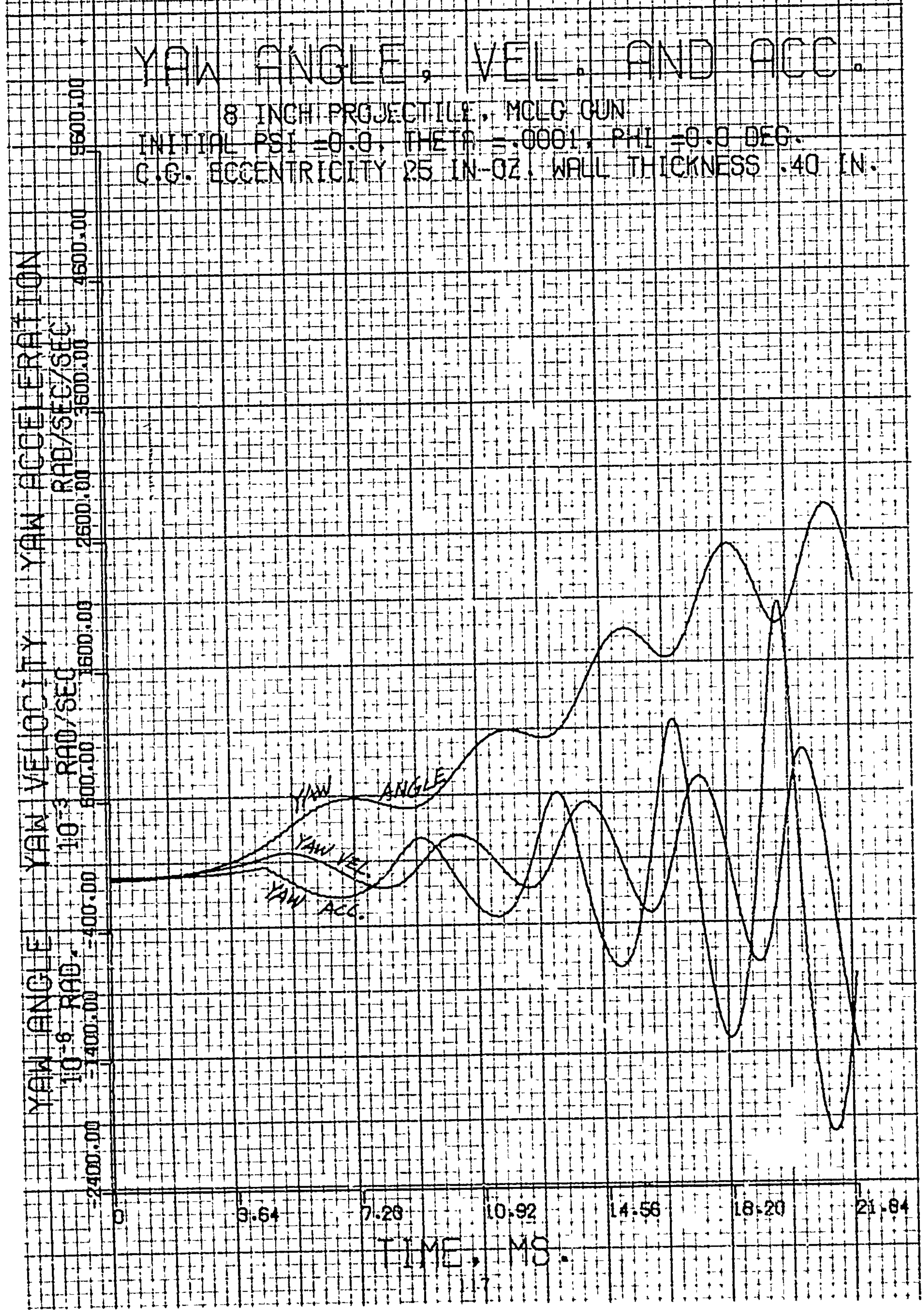

YAW ANGLE, VEL. AND ACC.
8 INCH PROJECTILE, MCLG GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .40 IN.
YAW ANGLE YAW VELOCITY YAW ACCELERATION
10-6 RAD. 10-3 RAD/SEC RAD/SEC/SEC
-2400.00
-1400.00
-400.00
600.00
1600.00
2600.00
3600.00
4600.00
9600.00
YAW ANGLE
YAW VEL.
YAW ACC.
0
3.64
7.28
10.92
14.56
18.20
21.84
TIME, MS.

FIGURE 35d

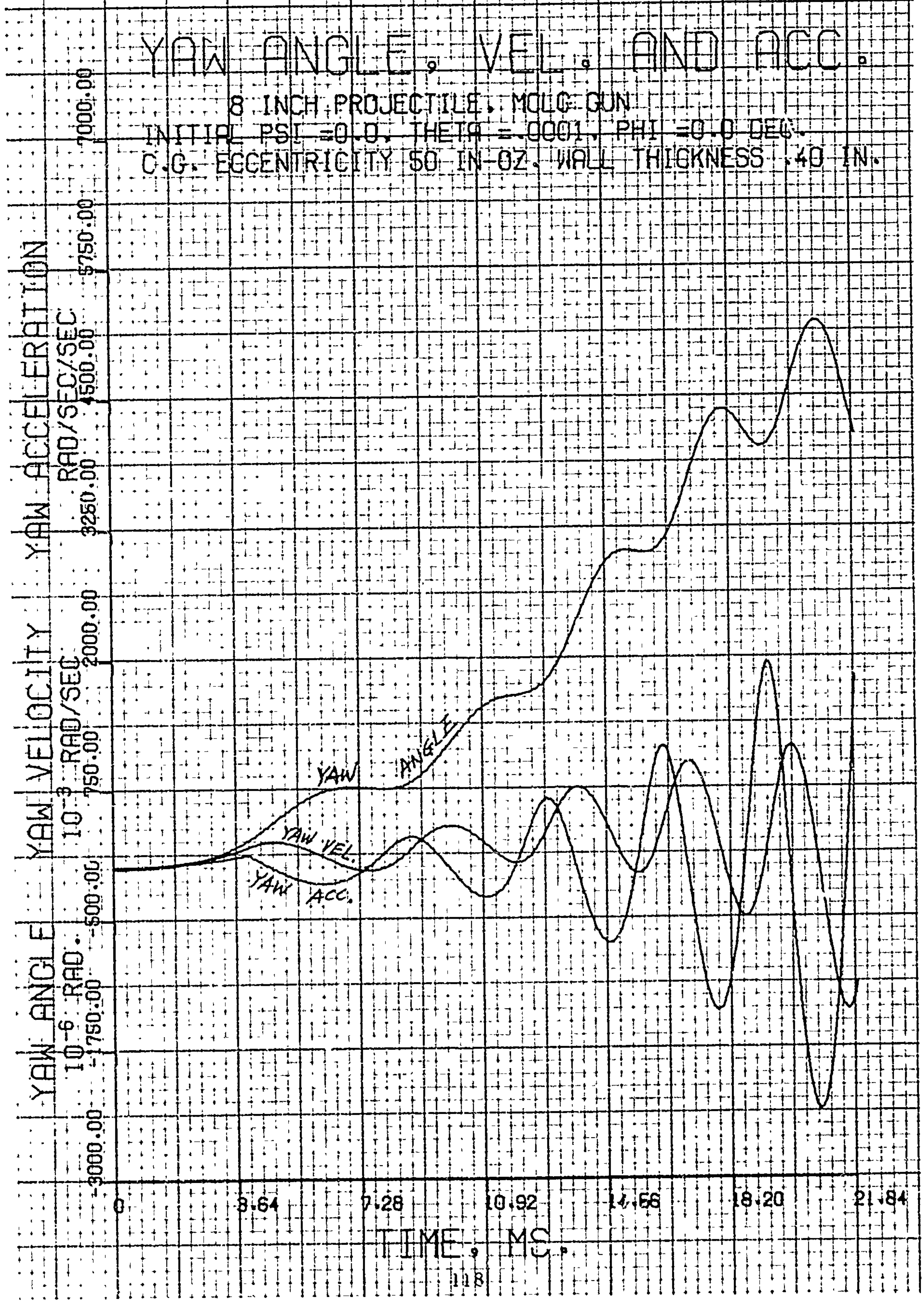
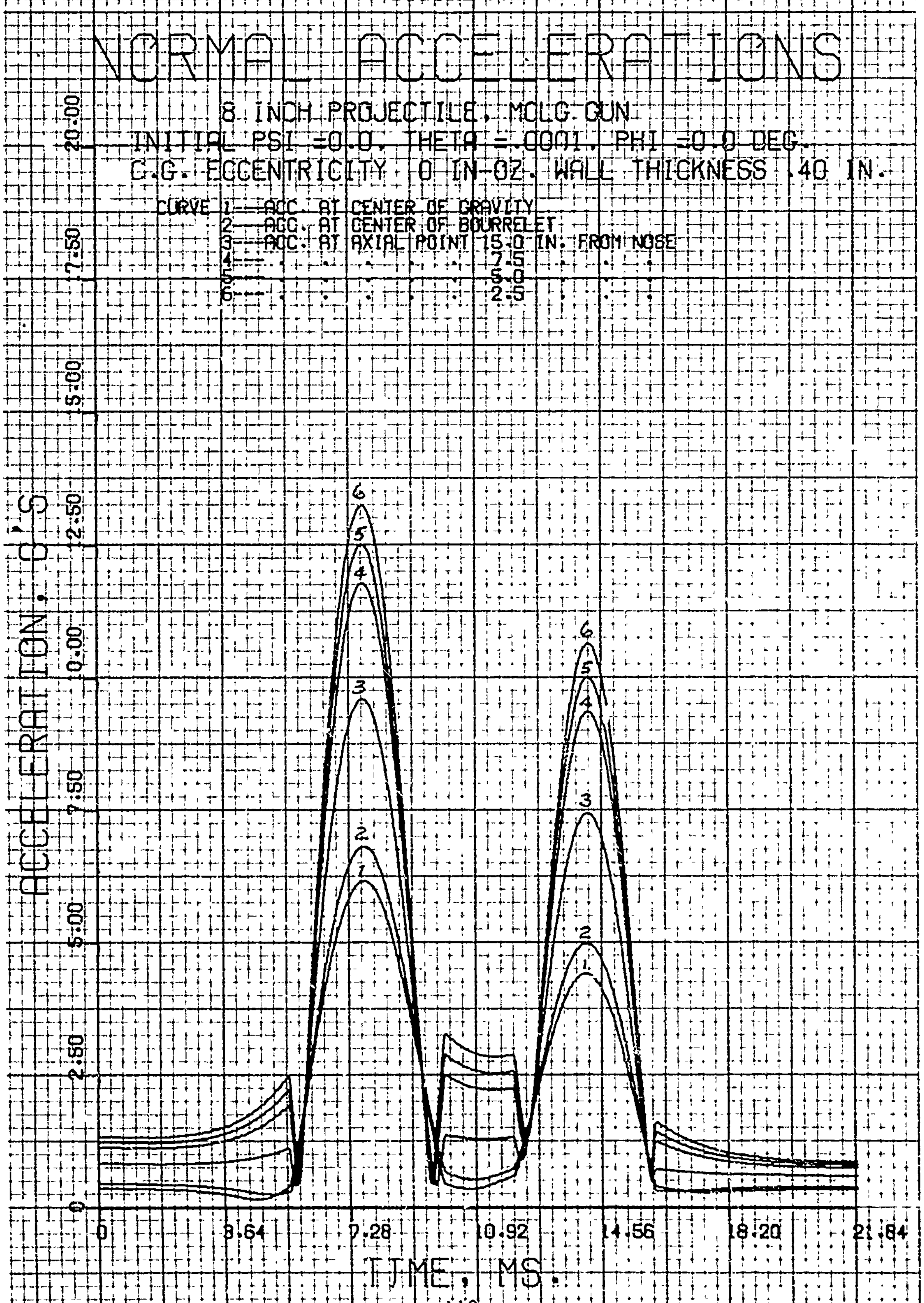

YAW ANGLE, VEL. AND ACC.
8 INCH PROJECTILE, MOLC GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ. WALL THICKNESS .40 IN.
YAW ANGLE YAW VELOCITY YAW ACCELERATION
10-6 RAD. 10-3 RAD/SEC RAD/SEC/SEC
-3000.00
-1750.00
-500.00
750.00
2000.00
3250.00
4500.00
5750.00
7000.00
YAW ANGLE
YAW VEL.
YAW ACC.
0
3.64
7.28
10.92
14.56
18.20
21.84
TIME, MS.

FIGURE 36a


NORMAL ACCELERATIONS
8 INCH PROJECTILE, MOLG GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ. WALL THICKNESS .40 IN.
CURVE 1---ACC. AT CENTER OF GRAVITY
2---ACC. AT CENTER OF BOURRELET
3---ACC. AT AXIAL POINT 15.0 IN. FROM NOSE
4--- " " " " 7.5
5--- " " " " 5.0
6--- " " " " 2.5
ACCELERATION, G'S
0
2.50
5.00
7.50
10.00
12.50
15.00
17.50
20.00
0
3.64
7.28
10.92
14.56
18.20
21.84
TIME, MS.

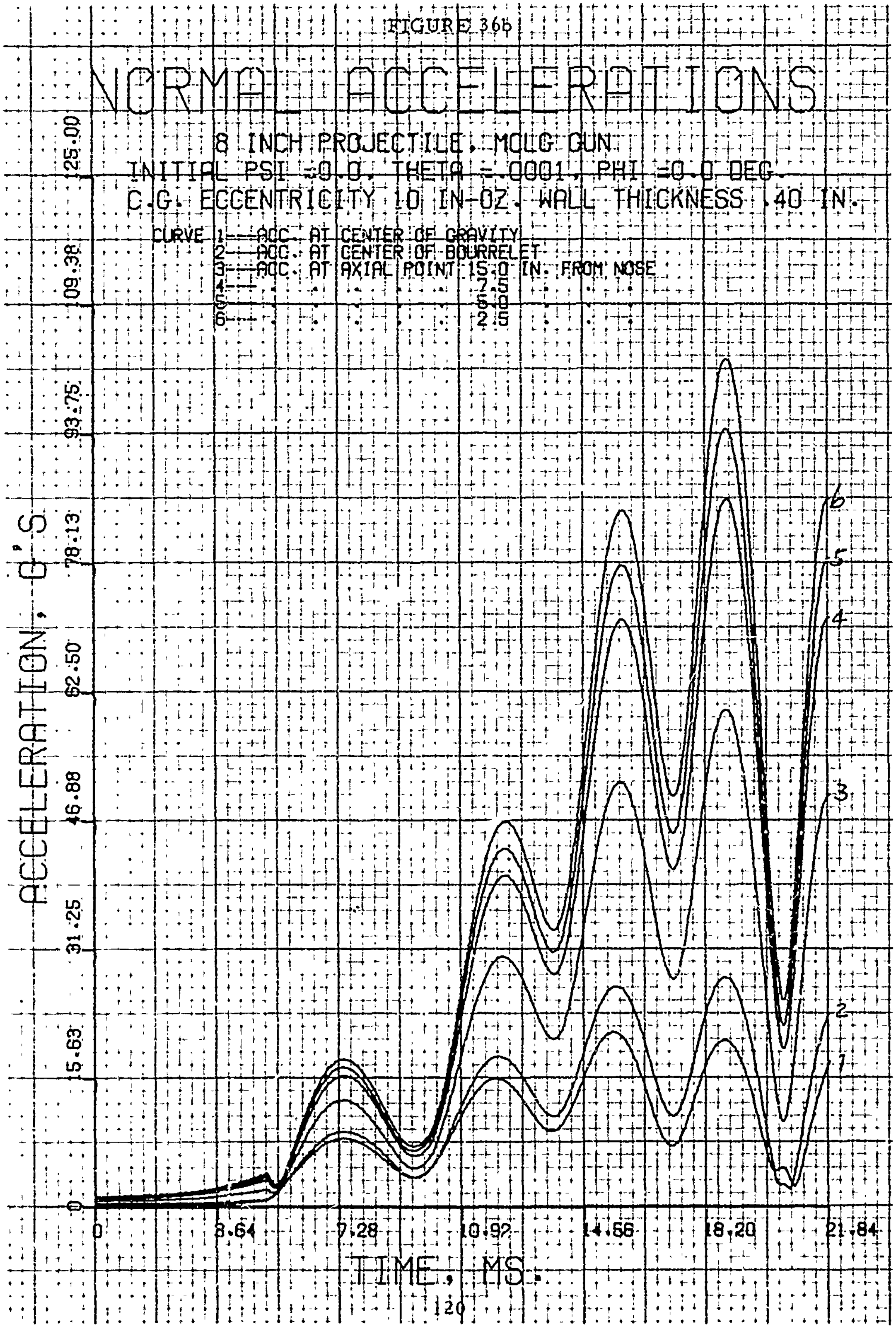


FIGURE 36b
NORMAL ACCELERATIONS
8 INCH PROJECTILE, MOLG GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ, WALL THICKNESS .40 IN.
CURVE 1---ACC. AT CENTER OF GRAVITY
2---ACC. AT CENTER OF BOURRELET
3---ACC. AT AXIAL POINT 15.0 IN. FROM NOSE
4--- 7.5
5--- 5.0
6--- 2.5
ACCELERATION, G'S
125.00
109.38
93.75
78.13
62.50
46.88
31.25
15.63
0
0
3.64
7.28
10.92
14.56
18.20
21.84
TIME, MS.
1
2
3
4
5
6

FIGURE 36c

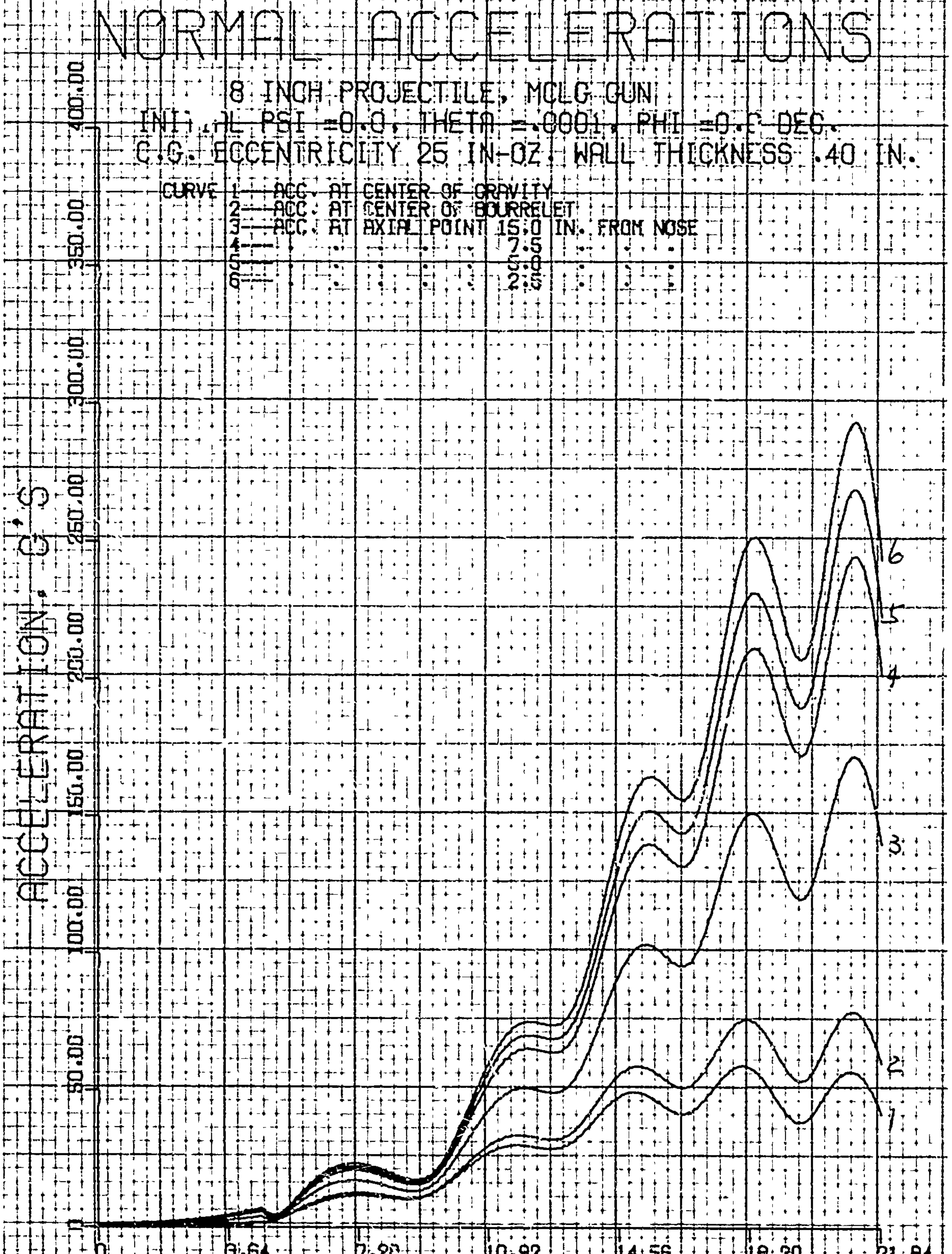

NORMAL ACCELERATIONS
8 INCH PROJECTILE, MCLG GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .40 IN.
CURVE 1 — ACC. AT CENTER OF GRAVITY
2 — ACC. AT CENTER OF BOURRELET
3 — ACC. AT AXIAL POINT 15.0 IN. FROM NOSE
4 — " " " " 7.5 " " "
5 — " " " " 5.0 " " "
6 — " " " " 2.5 " " "
ACCELERATION, G'S
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0
3.64
7.28
10.92
14.56
18.20
21.84
TIME, MS.
1
2
3
4
5
6

FIGURE 36d

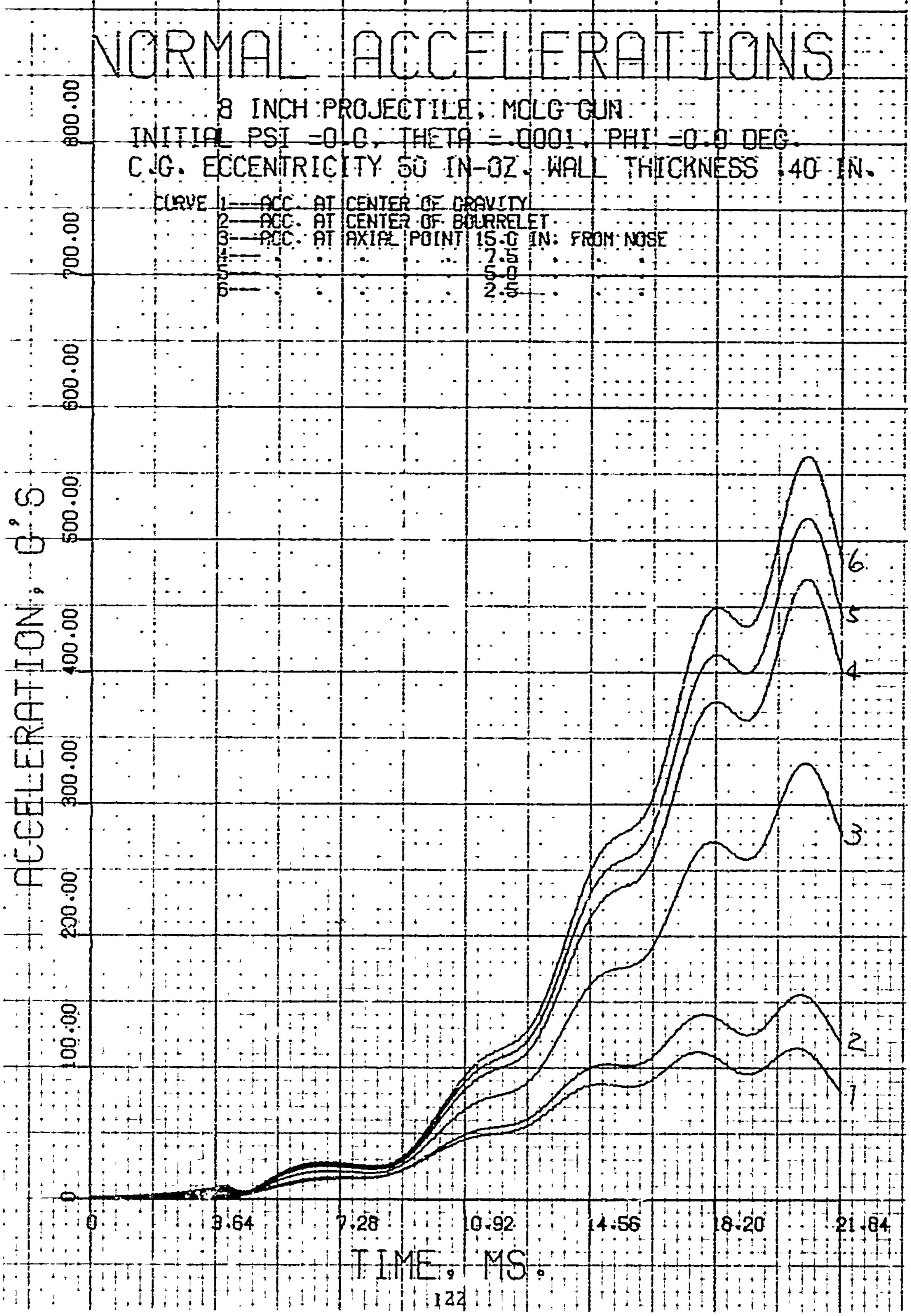

NORMAL ACCELERATIONS
8 INCH PROJECTILE, MCLG GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ. WALL THICKNESS .40 IN.
CURVE 1---ACC. AT CENTER OF GRAVITY
2---ACC. AT CENTER OF BOURRELET
3---ACC. AT AXIAL POINT 15.0 IN. FROM NOSE
4--- 7.5
5--- 5.0
6--- 2.5
ACCELERATION, G'S
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0
0
3.64
7.28
10.92
14.56
18.20
21.84
TIME, MS.
1
2
3
4
5
6

FIGURE 37a

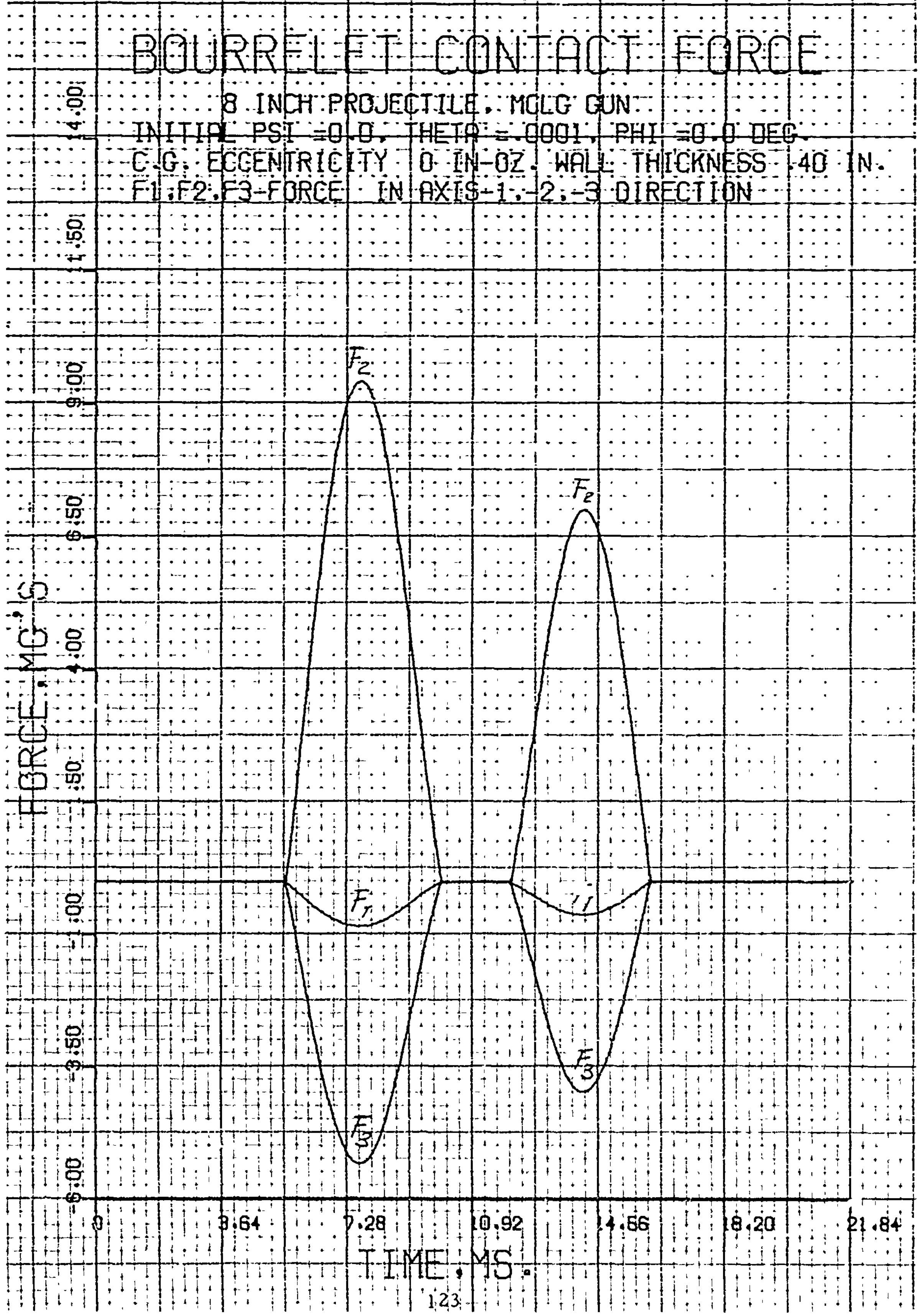

BOURRELET CONTACT FORCE
8 INCH PROJECTILE, MCLG GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ. WALL THICKNESS .40 IN.
F1,F2,F3-FORCE IN AXIS-1,-2,-3 DIRECTION
FORCE, MG'S
TIME, MS.
14.00
11.50
9.00
6.50
4.00
1.50
-1.00
-3.50
-6.00
0
3.64
7.28
10.92
14.56
18.20
21.84
F2
F1
F3

FIGURE 37b

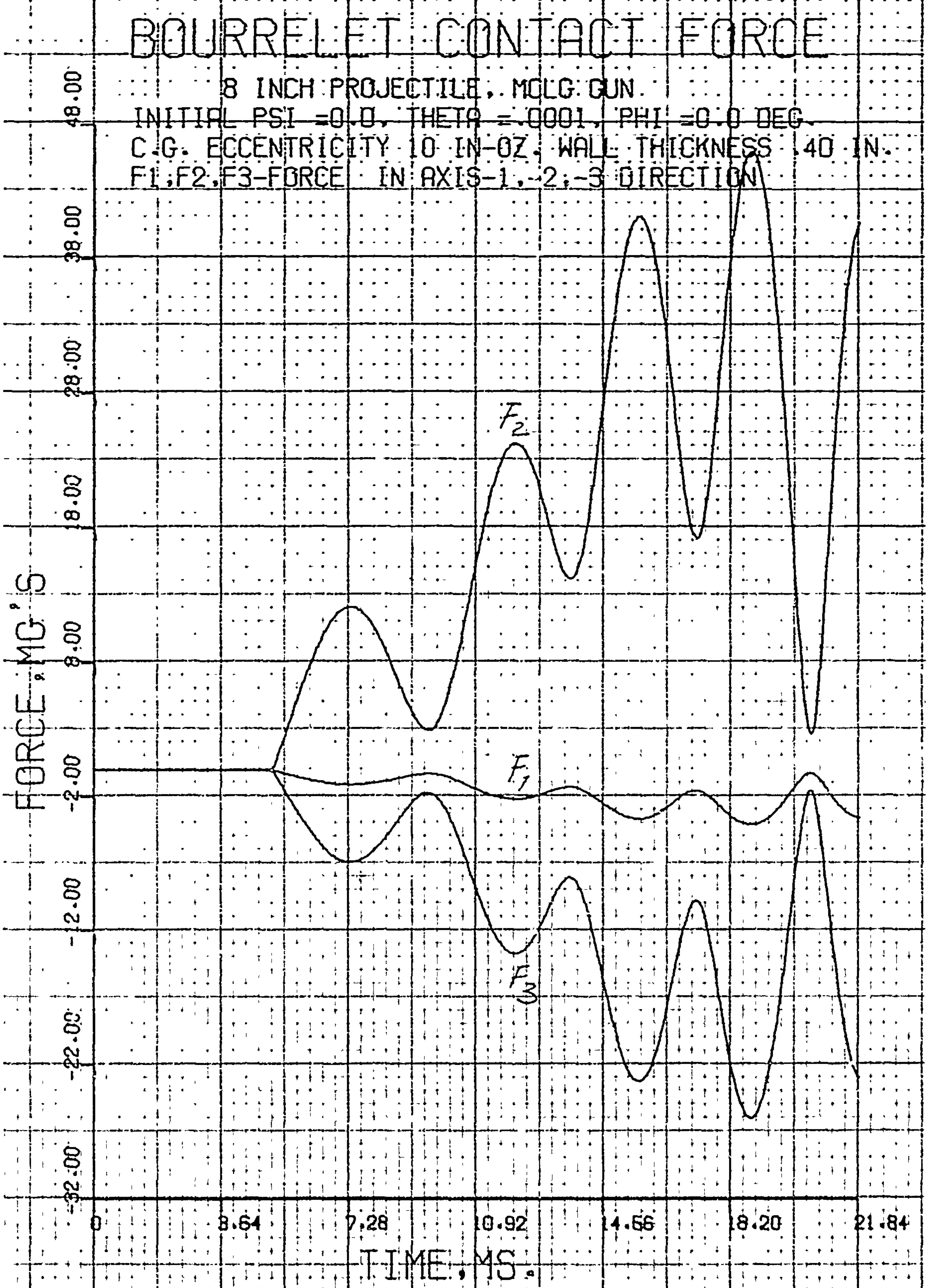

BOURRELET CONTACT FORCE
8 INCH PROJECTILE, MOLG GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ, WALL THICKNESS .40 IN.
F1,F2,F3-FORCE IN AXIS-1,-2,-3 DIRECTION
F2
F1
F3
FORCE,MG'S
48.00
38.00
28.00
18.00
8.00
-2.00
-12.00
-22.00
-32.00
0
3.64
7.28
10.92
14.56
18.20
21.84
TIME,MS.

FIGURE 37c

BOURRELET CONTACT FORCE

8 INCH PROJECTILE, MCLG GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ, WALL THICKNESS .40 IN.
F1,F2,F3=FORCE IN AXIS=1,-2,-3 DIRECTION

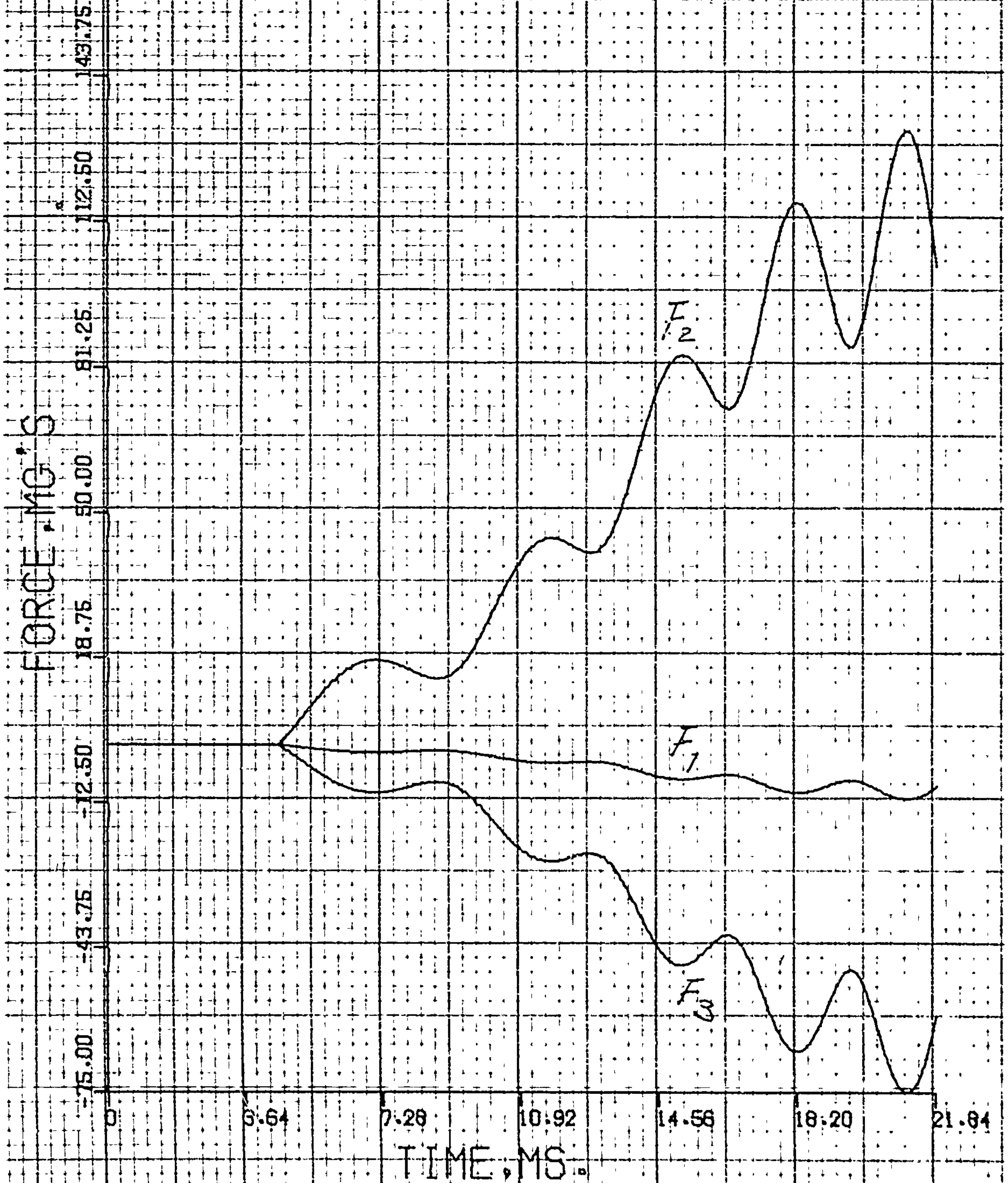
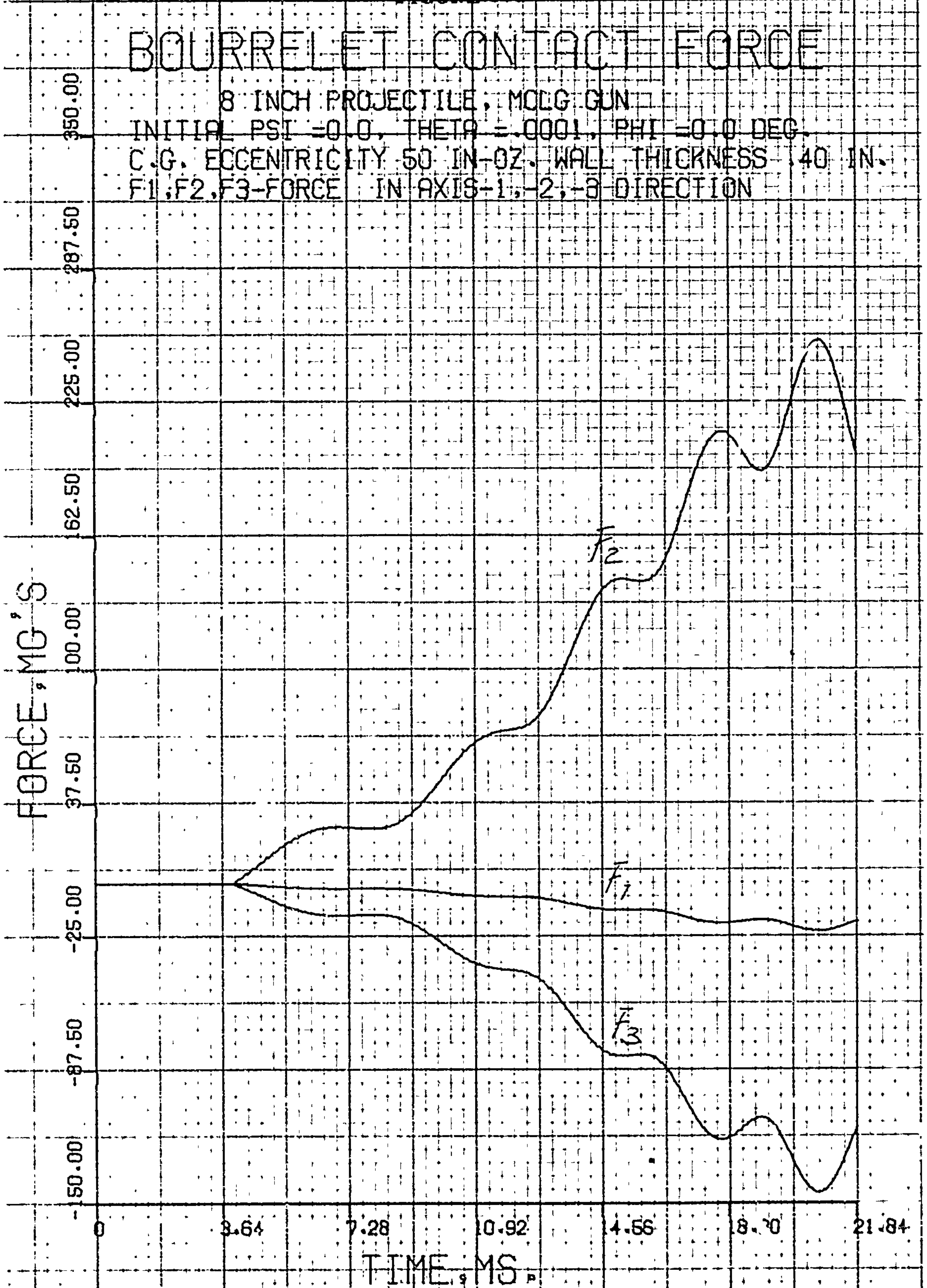
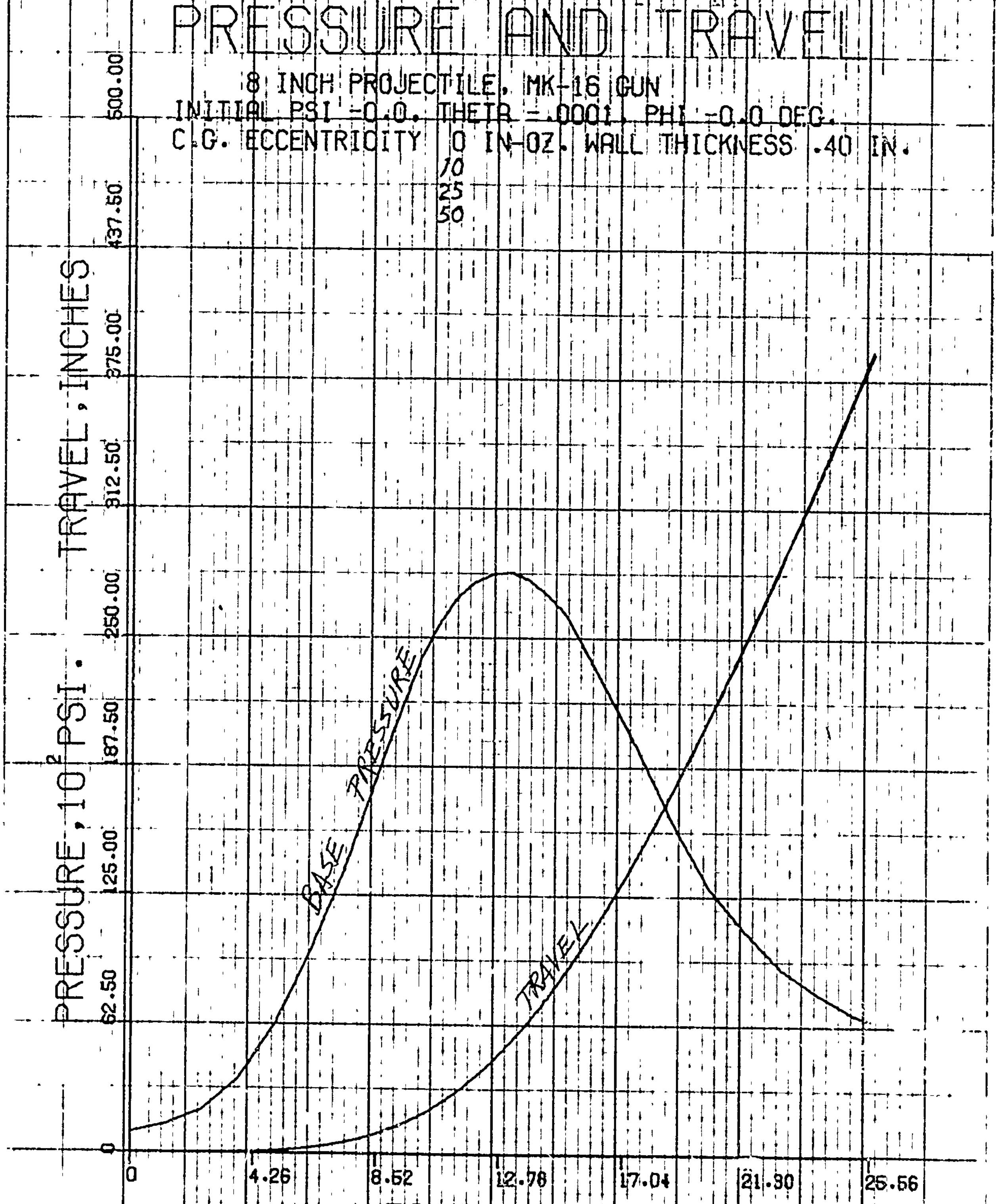


FIGURE 37d


BOURRELET CONTACT FORCE
8 INCH PROJECTILE, MOLG GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ. WALL THICKNESS .40 IN.
F1,F2,F3-FORCE IN AXIS-1,-2,-3 DIRECTION
FORCE, MG'S
350.00
287.50
225.00
162.50
100.00
37.50
-25.00
-87.50
-150.00
0
3.64
7.28
10.92
14.56
18.20
21.84
TIME, MS.
$\bar{F}_2$
$\bar{F}_1$
$\bar{F}_3$

MK-16 GUN

FIGURE 38 **CONFIDENTIAL**



CONFIDENTIAL

FIGURE 39

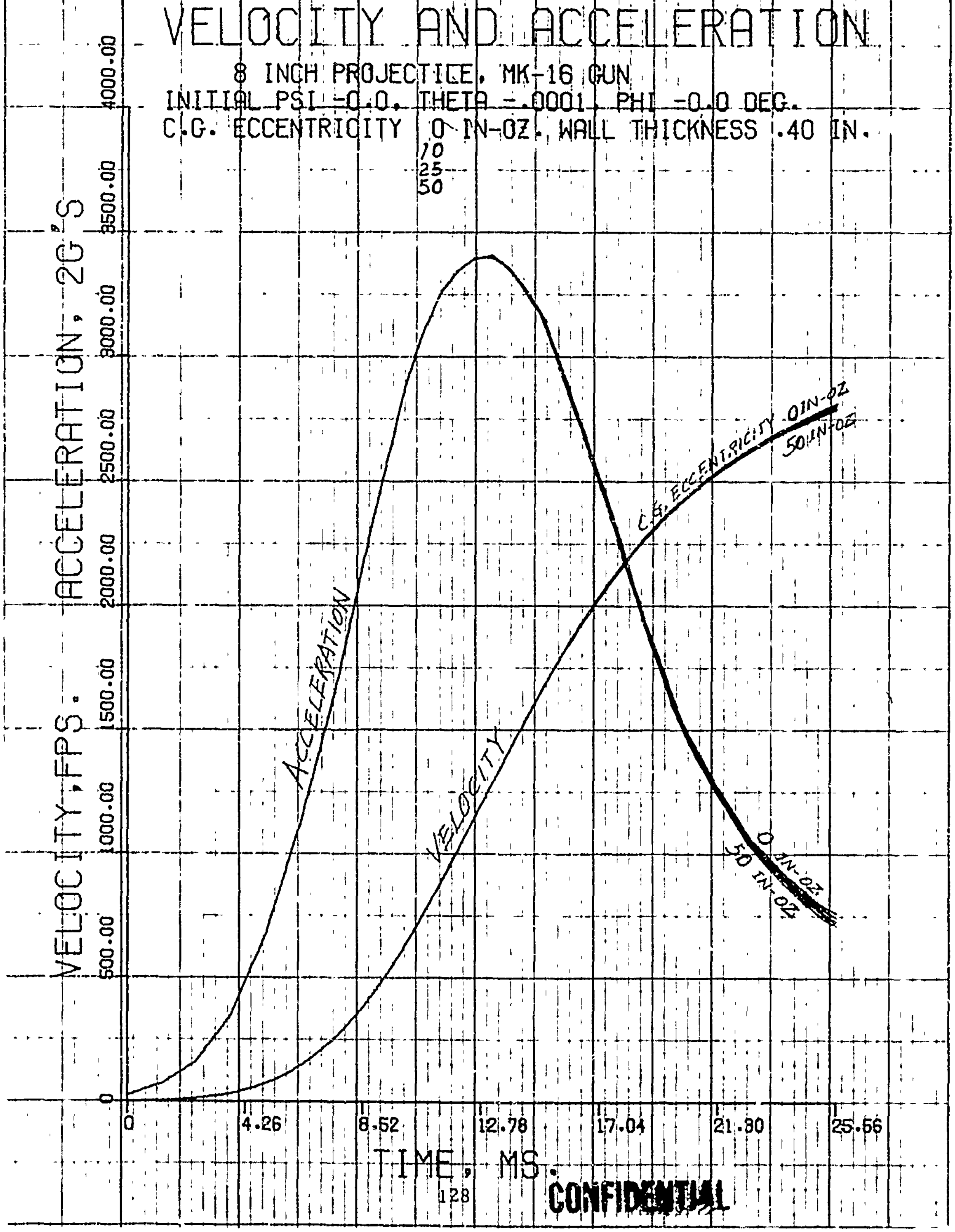
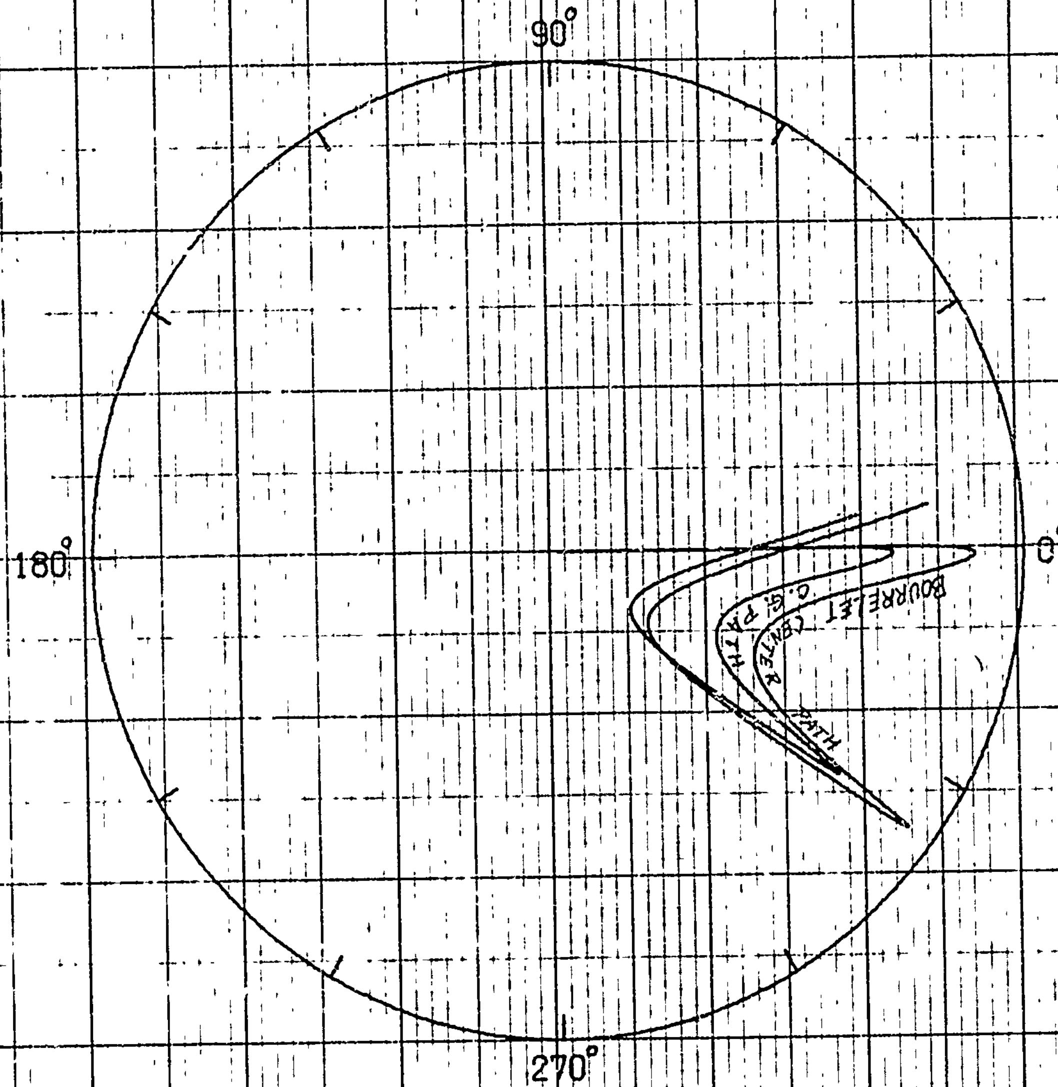

VELOCITY AND ACCELERATION
8 INCH PROJECTILE, MK-16 GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ, WALL THICKNESS .40 IN.
10
25
50
VELOCITY, FPS. ACCELERATION, 2G'S
4000.00
3500.00
3000.00
2500.00
2000.00
1500.00
1000.00
500.00
0
0
4.26
8.52
12.78
17.04
21.30
25.56
TIME, MS.
ACCELERATION
VELOCITY
C.G. ECCENTRICITY 0 IN-OZ
50 IN-OZ
0 IN-OZ
50 IN-OZ

FIGURE 9a

C.G. AND BOURRELET CENTER

8 INCH PROJECTILE, MK-16 GUN
INITIAL PSI -0.0, THETA -.0001, PHI -0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ. WALL THICKNESS .40 IN.



R= .0050 IN.

FIGURE 40b

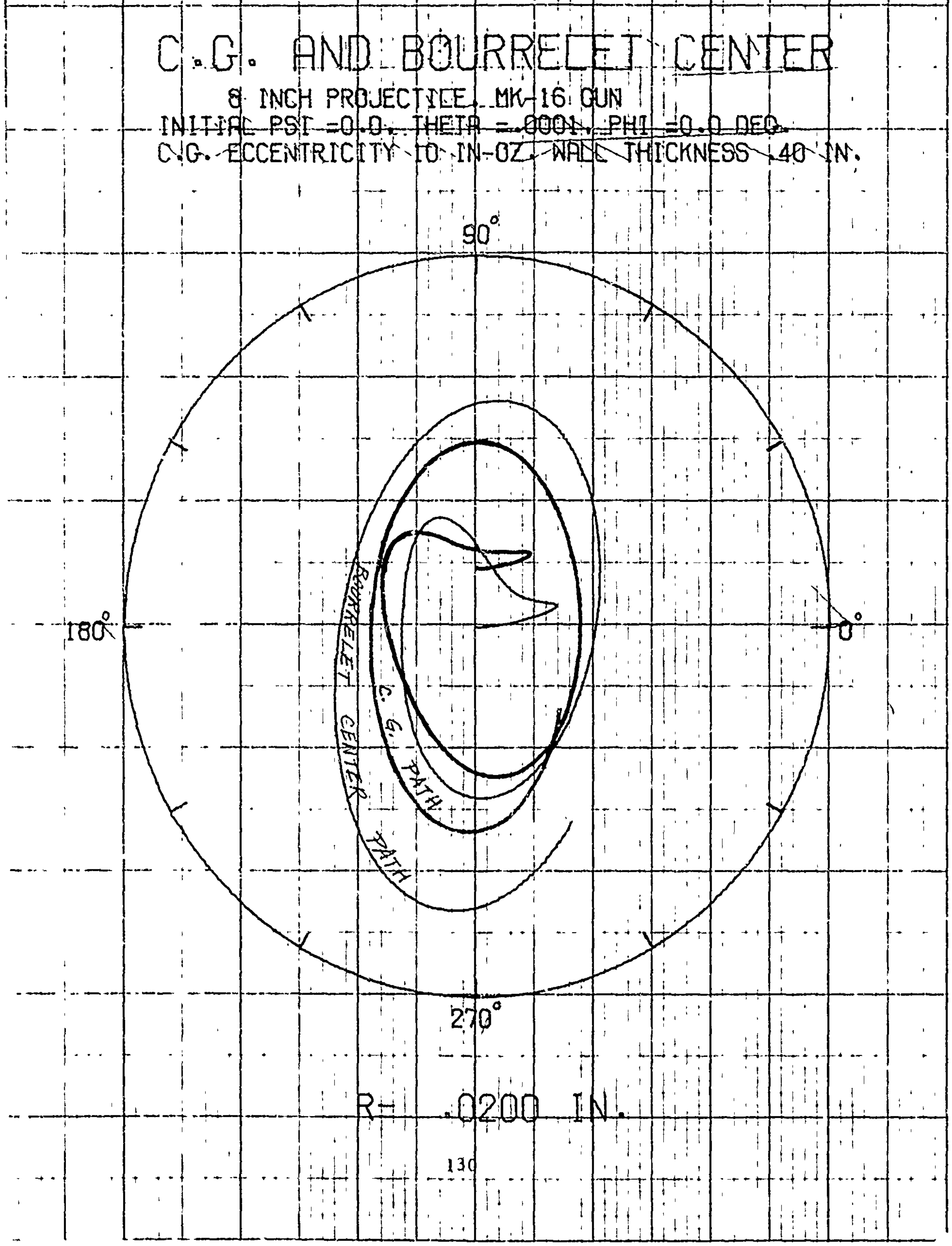

C.G. AND BOURRECET CENTER
8 INCH PROJECTICE, MK-16 GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ, WALL THICKNESS .40 IN.
90°
180°
0°
270°
BOURRELET CENTER PATH
C. G. PATH
R= .0200 IN.

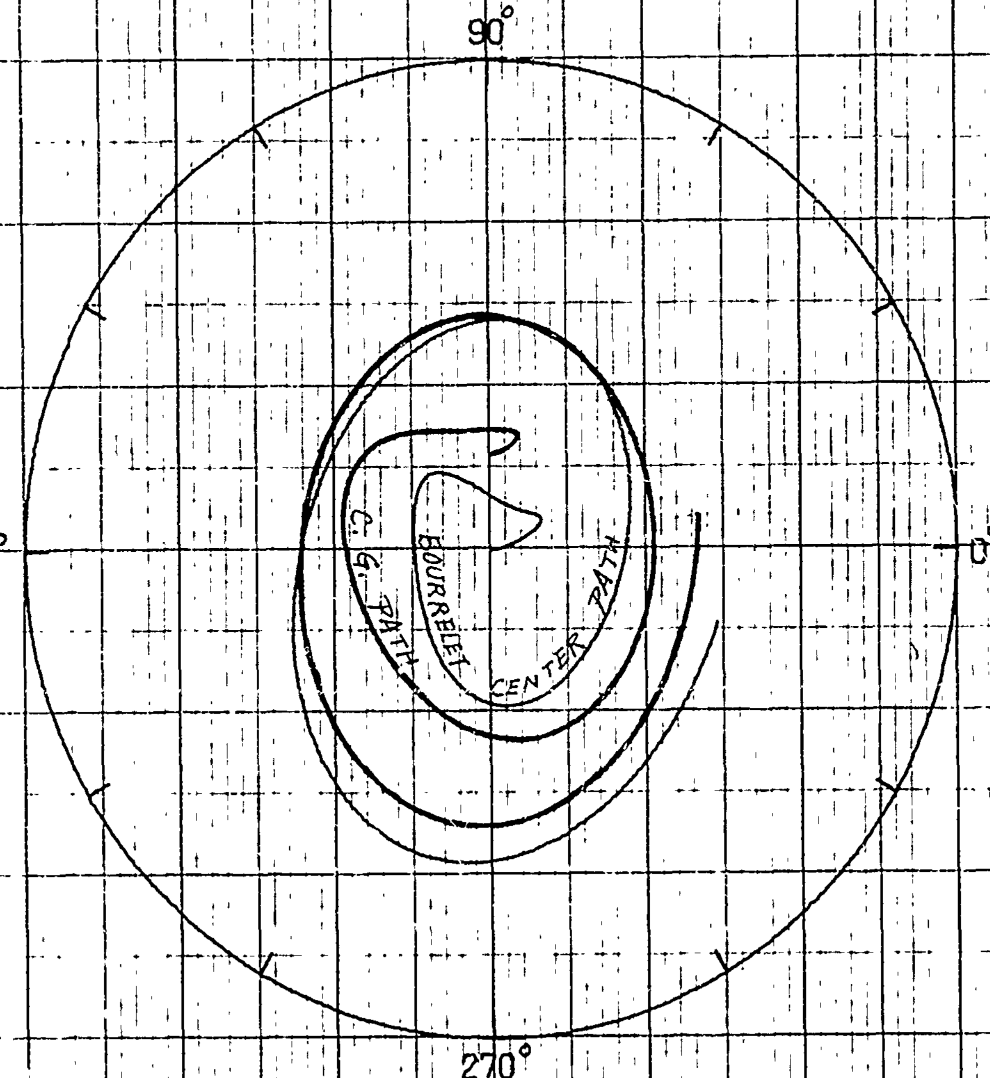
FIGURE 40c

C.G. AND BOURRELET CENTER

8 INCH PROJECTILE, MK 16 GUN

INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.

C.G. ECCENTRICITY 25 IN-OZ, WALL THICKNESS .40 IN.

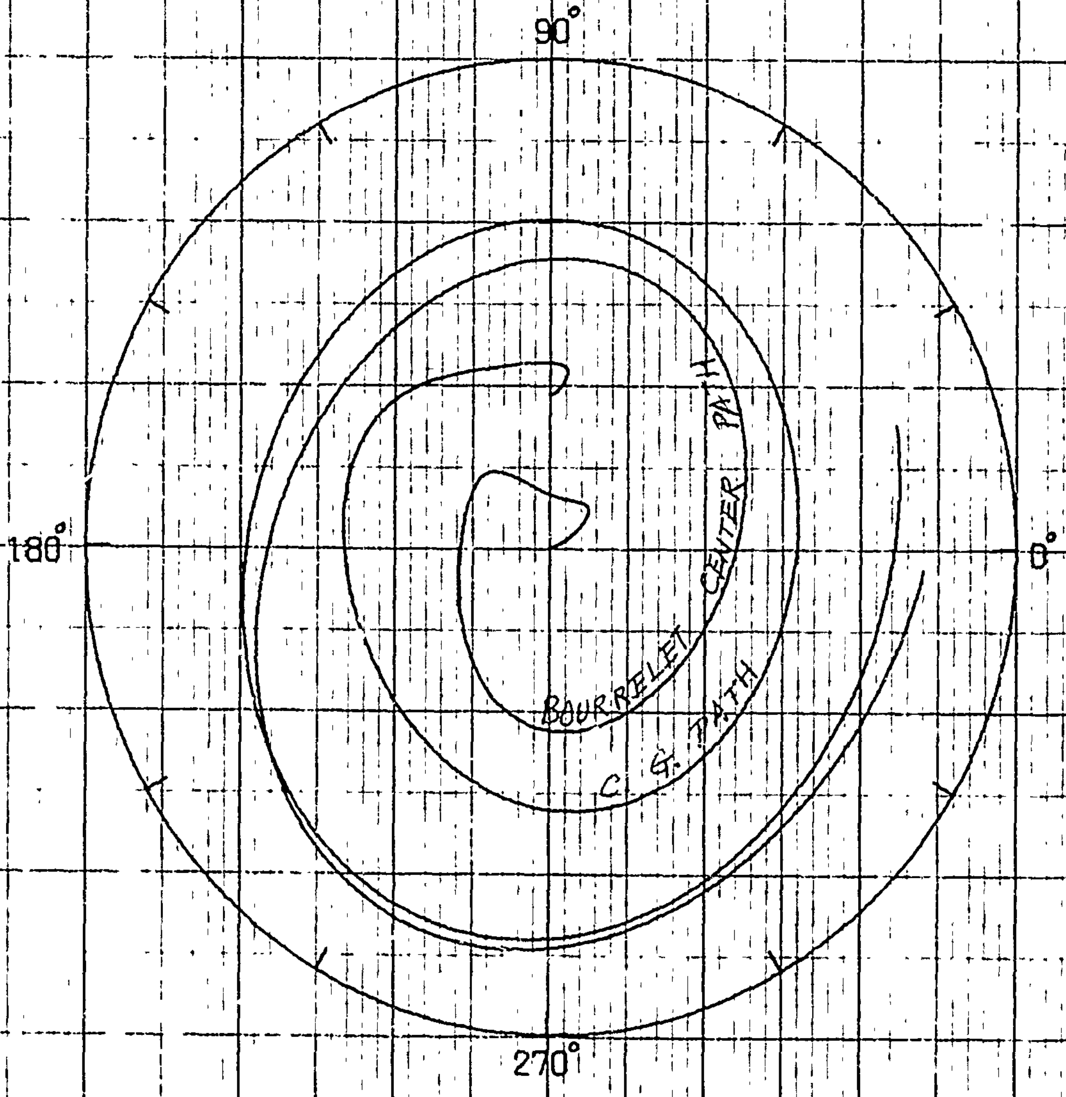


R= .0400 IN.

FIGURE 40d

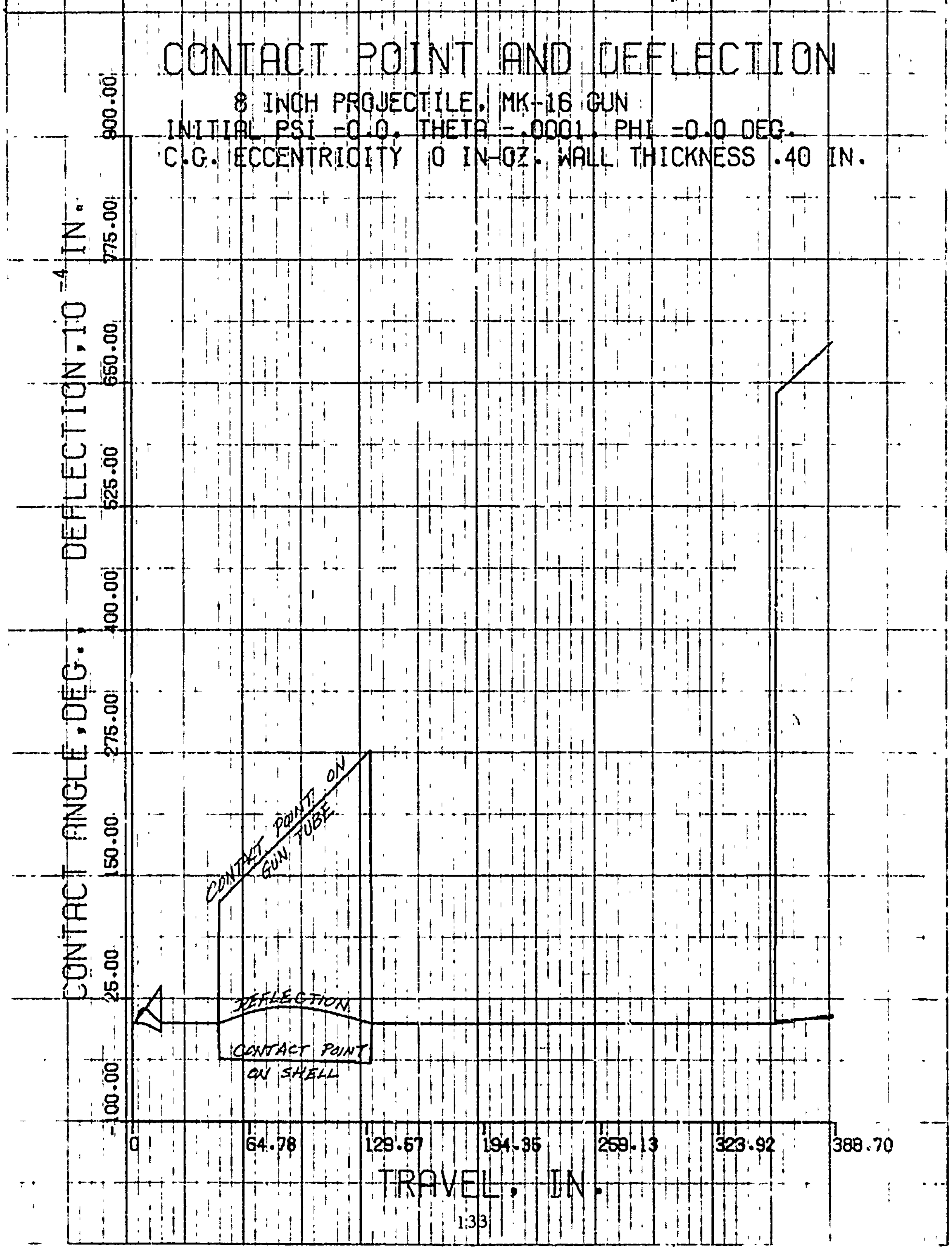
C.G. AND BOURRELET CENTER

8 INCH PROJECTILE, MK-16 GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ. WALL THICKNESS .40 IN.



R= .0500 IN.

FIGURE 41a



CONTACT POINT AND DEFLECTION
8 INCH PROJECTILE, MK-16 GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ. WALL THICKNESS .40 IN.
CONTACT ANGLE, DEG. DEFLECTION, 10 -4 IN.
900.00
775.00
650.00
525.00
400.00
275.00
150.00
25.00
-100.00
CONTACT POINT ON GUN TUBE
DEFLECTION
CONTACT POINT ON SHELL
0
64.78
129.57
194.35
259.13
323.92
388.70
TRAVEL, IN.

FIGURE 41b

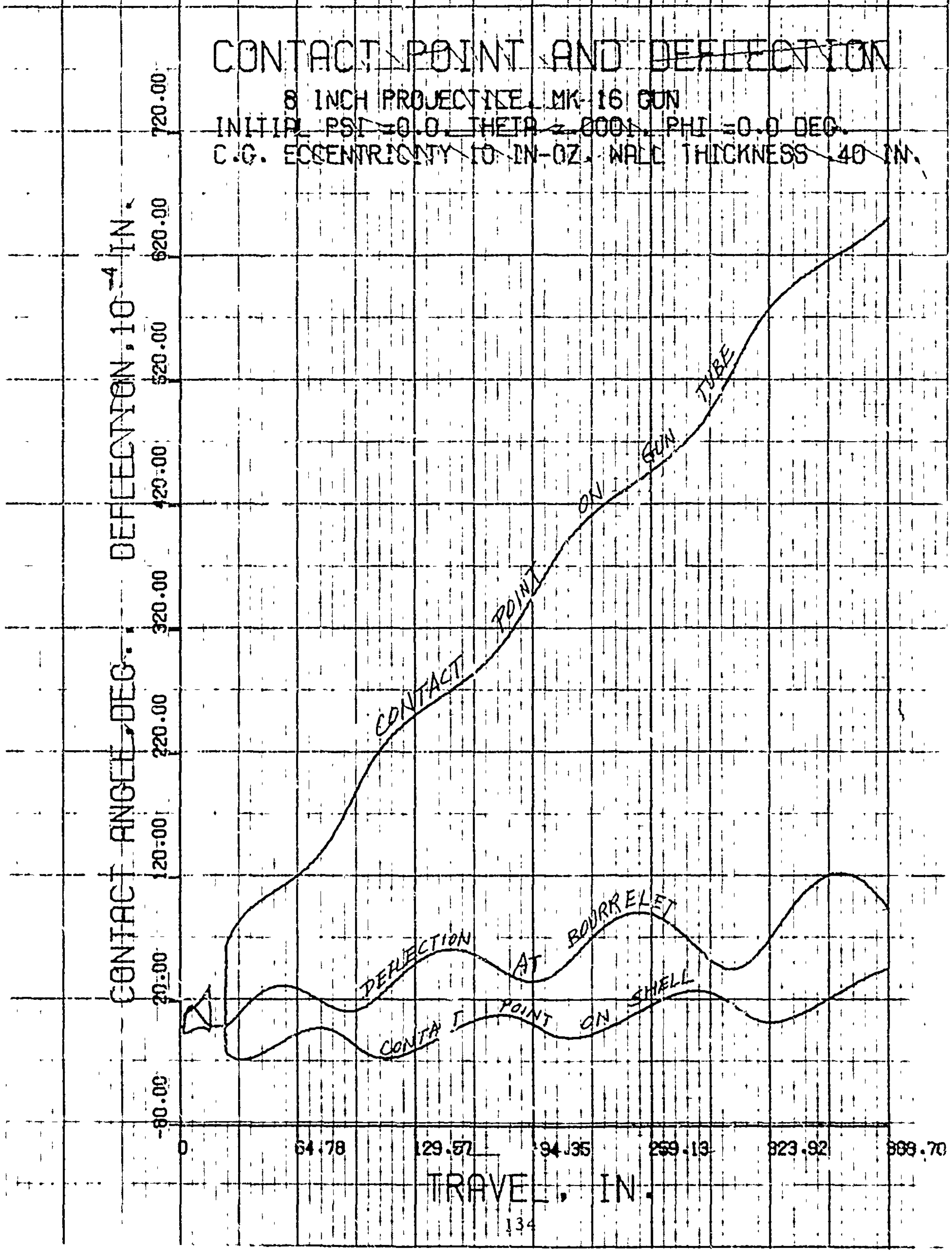
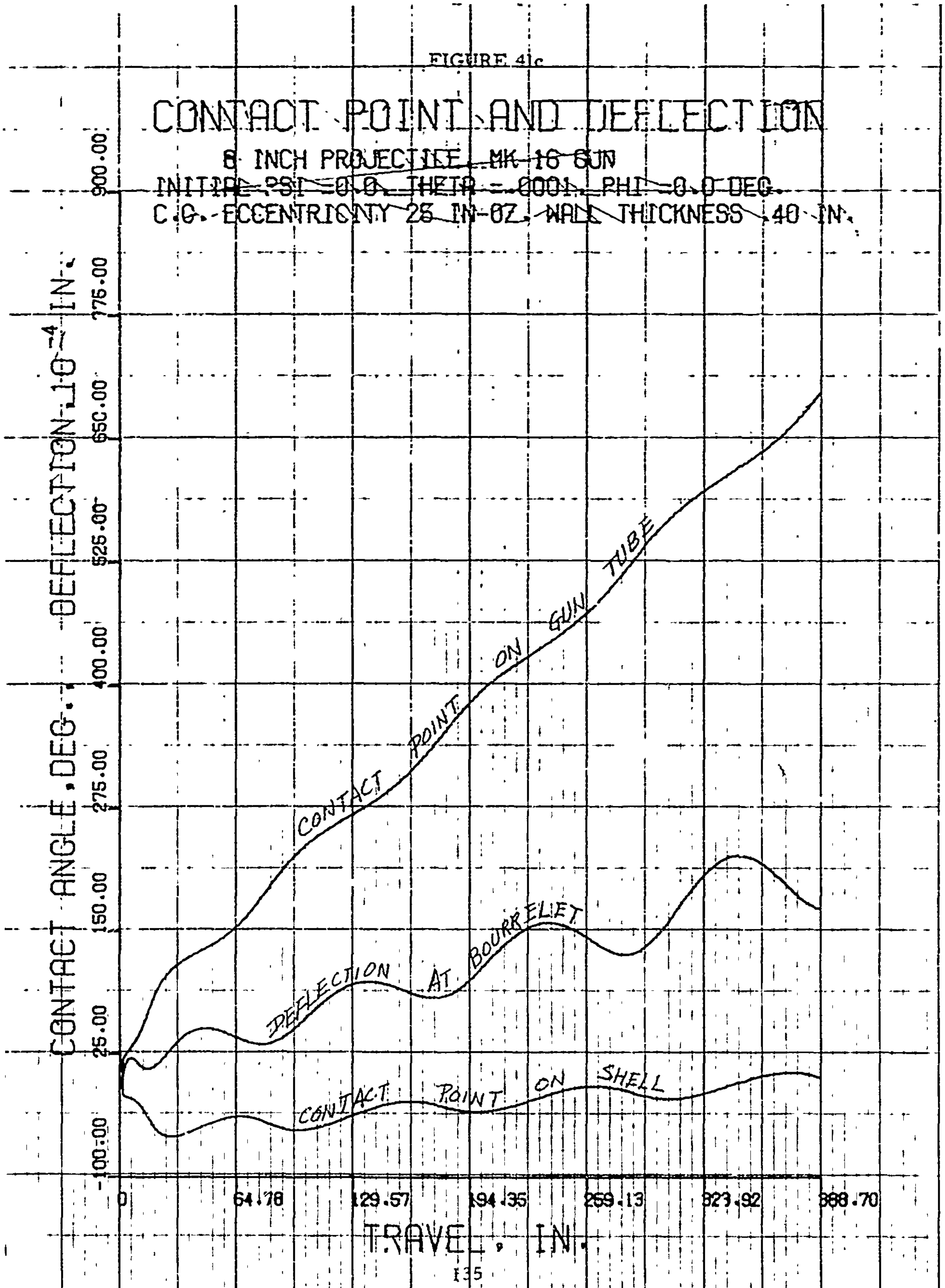

CONTACT POINT AND DEFLECTION
8 INCH PROJECTILE, MK-16 GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ. WALL THICKNESS .40 IN.
CONTACT ANGLE, DEG. DEFLECTION, 10^-4 IN.
720.00
620.00
520.00
420.00
320.00
220.00
120.00
20.00
-80.00
0
64.78
129.57
194.35
259.13
323.92
388.70
TRAVEL, IN.
CONTACT POINT ON GUN TUBE
DEFLECTION AT BOURRELET
CONTACT POINT ON SHELL

FIGURE 41c



CONTACT POINT AND DEFLECTION
8 INCH PROJECTILE MK 16 GUN
INITIAL PSI =0.0 THETA =.0001 PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .40 IN.
CONTACT ANGLE, DEG., DEFLECTION, 10⁻⁴ IN.
900.00
775.00
650.00
525.00
400.00
275.00
150.00
25.00
-100.00
0
64.78
129.57
194.35
259.13
323.92
388.70
TRAVEL, IN.
CONTACT POINT ON GUN TUBE
DEFLECTION AT BOURRELET
CONTACT POINT ON SHELL

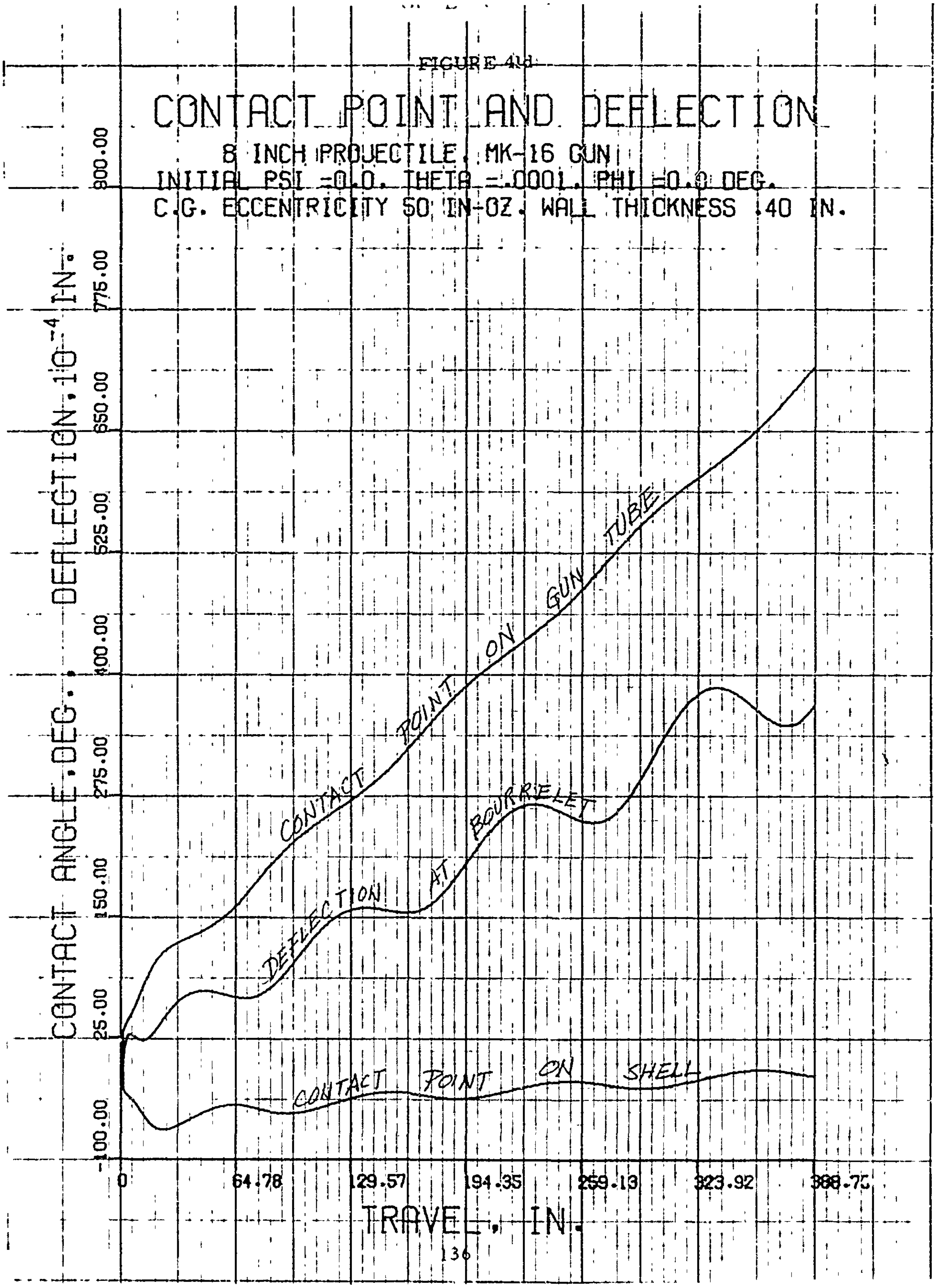

CONTACT POINT AND DEFLECTION
8 INCH PROJECTILE, MK-16 GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ, WALL THICKNESS .40 IN.
CONTACT ANGLE, DEG., DEFLECTION, 10^{-4} IN.
-100.00
25.00
150.00
275.00
400.00
525.00
650.00
775.00
900.00
0
64.78
129.57
194.35
259.13
323.92
388.70
TRAVEL, IN.
CONTACT POINT ON GUN TUBE
DEFLECTION AT BOURRELET
CONTACT POINT ON SHELL
FIGURE 4d

FIGURE 42a

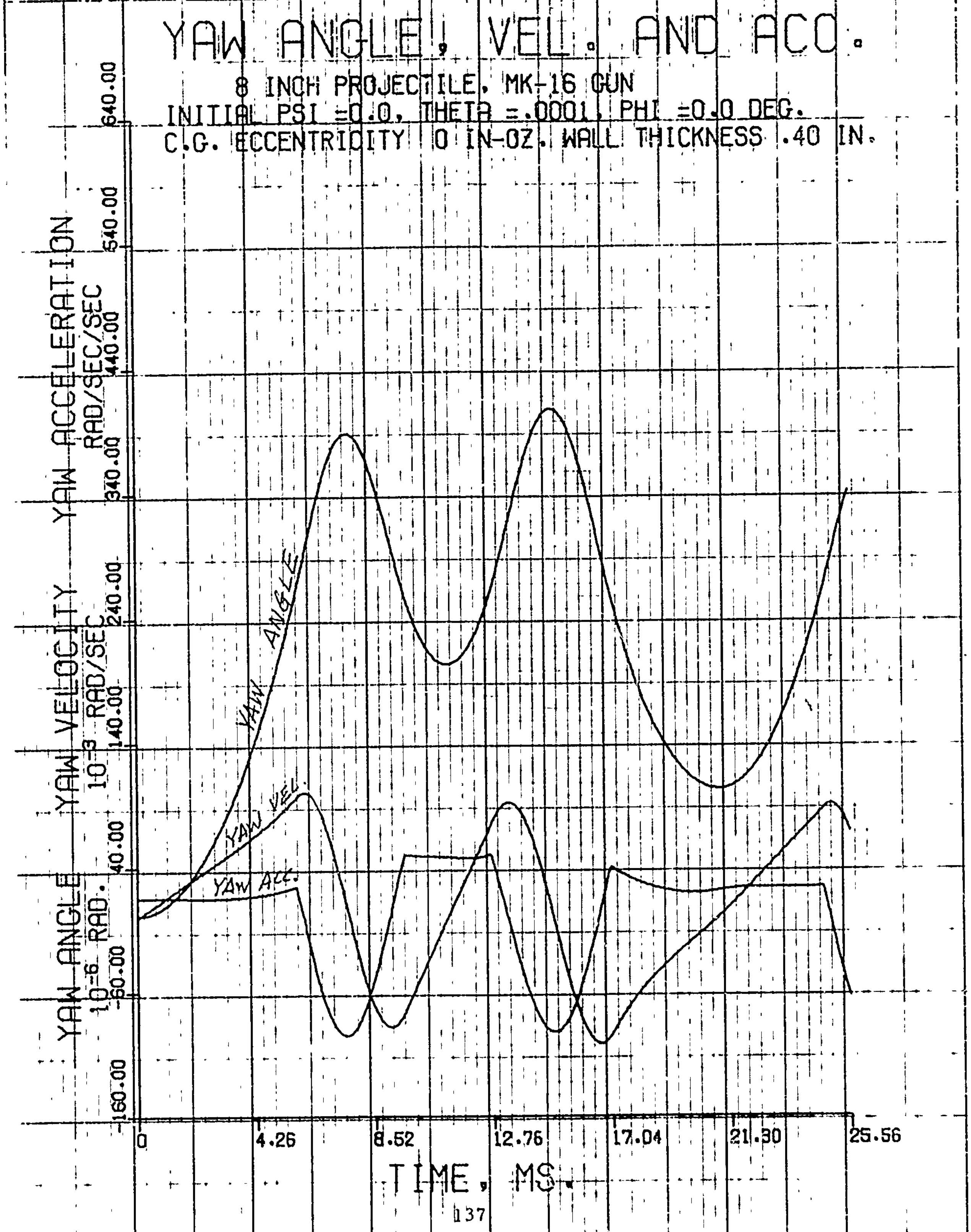

YAW ANGLE, VEL. AND ACC.
8 INCH PROJECTILE, MK-16 GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ. WALL THICKNESS .40 IN.
YAW ANGLE 10-6 RAD.
YAW VELOCITY 10-3 RAD/SEC
YAW ACCELERATION RAD/SEC/SEC
640.00
540.00
440.00
340.00
240.00
140.00
40.00
-60.00
-160.00
YAW ANGLE
YAW VEL.
YAW ACC.
0
4.26
8.52
12.76
17.04
21.30
25.56
TIME, MS.

FIGURE 42b

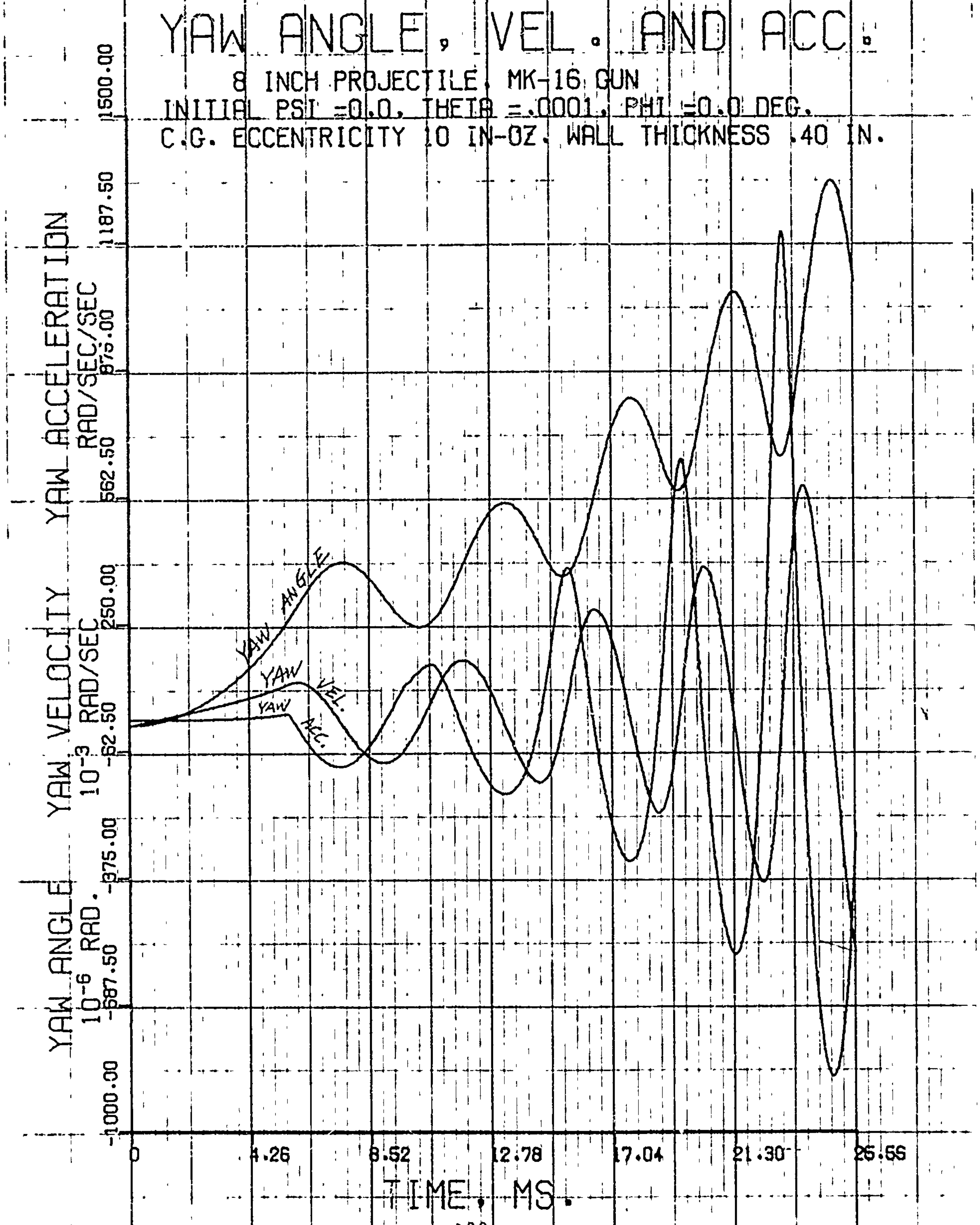

YAW ANGLE, VEL. AND ACC.
8 INCH PROJECTILE, MK-16 GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ, WALL THICKNESS .40 IN.
YAW ACCELERATION
RAD/SEC/SEC
YAW VELOCITY
10^{-3} RAD/SEC
YAW ANGLE
10^{-6} RAD.
1500.00
1187.50
875.00
562.50
250.00
-62.50
-375.00
-687.50
-1000.00
YAW ANGLE
YAW VEL.
YAW ACC.
0
4.26
8.52
12.78
17.04
21.30
25.56
TIME, MS.

FIGURE 42c

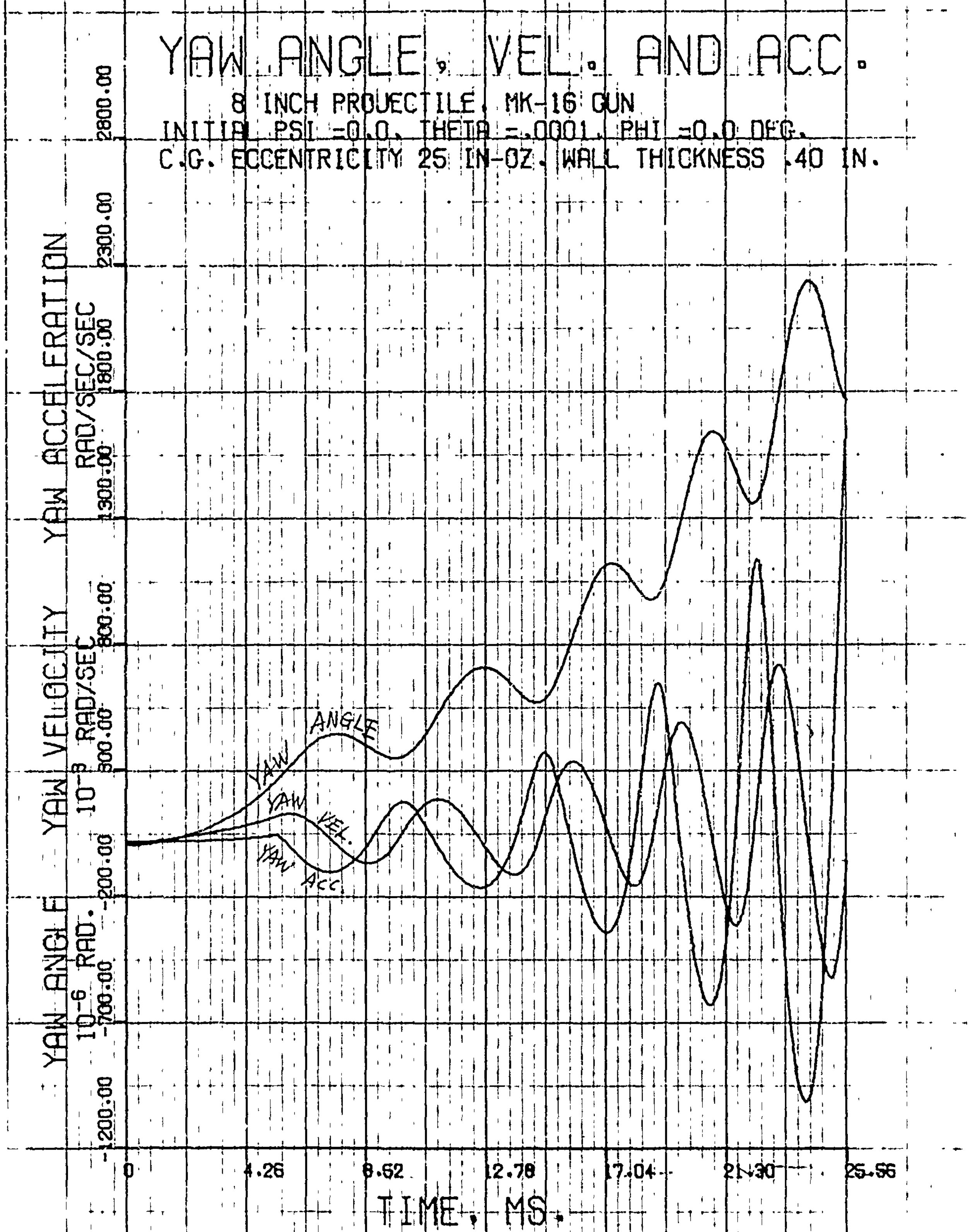

YAW ANGLE, VEL. AND ACC.
8 INCH PROJECTILE, MK-16 GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .40 IN.
YAW ANGLE 10-6 RAD.
YAW VELOCITY 10-3 RAD/SEC
YAW ACCELERATION RAD/SEC/SEC
2800.00
2300.00
1800.00
1300.00
800.00
300.00
-200.00
-700.00
-1200.00
0
4.26
8.52
12.78
17.04
21.30
25.56
TIME, MS.
YAW ANGLE
YAW VEL.
YAW ACC.

FIGURE 42d

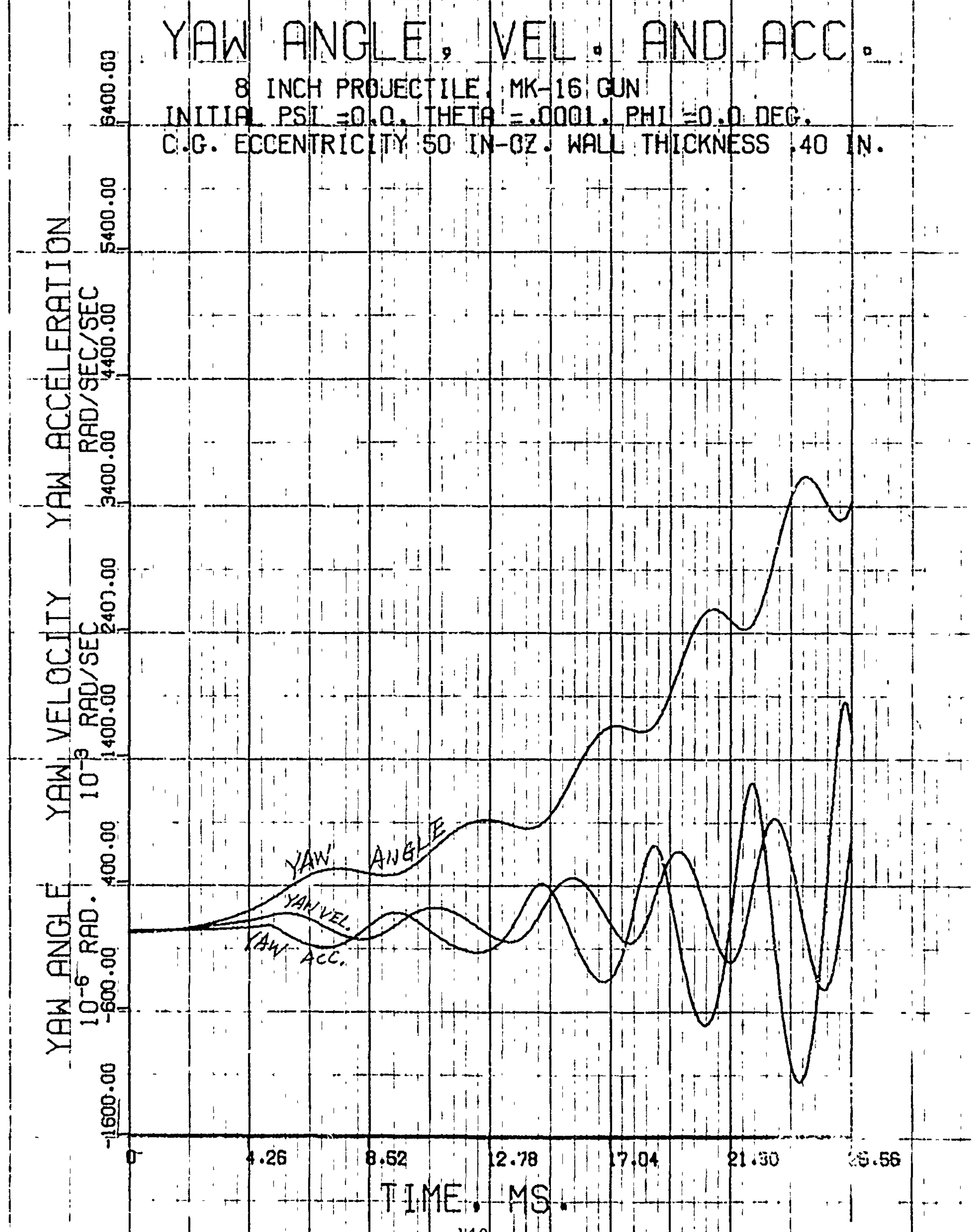
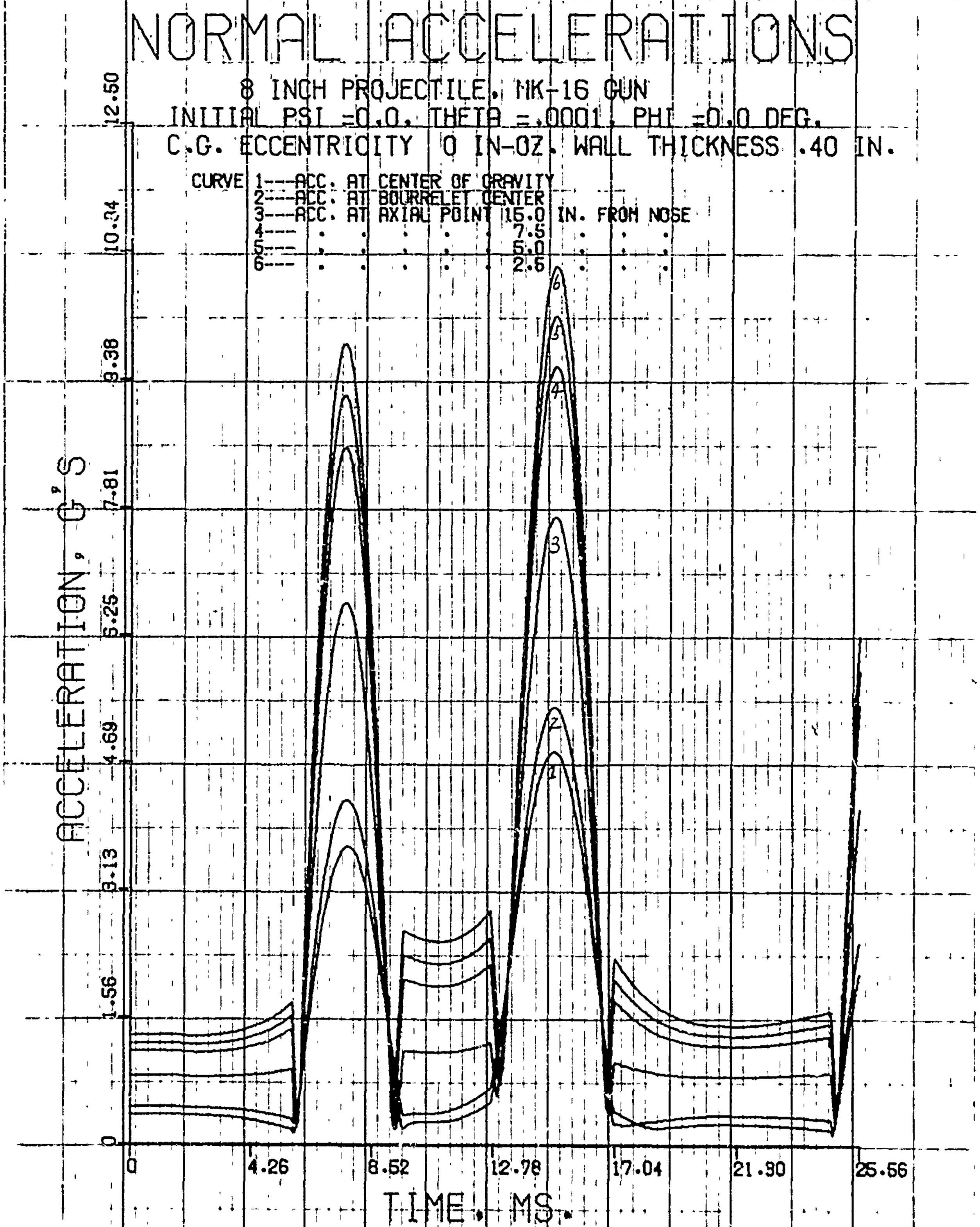

YAW ANGLE, VEL. AND ACC.
8 INCH PROJECTILE, MK-16 GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ. WALL THICKNESS .40 IN.
YAW ANGLE 10-6 RAD.
YAW VELOCITY 10-3 RAD/SEC
YAW ACCELERATION RAD/SEC/SEC
6400.00
5400.00
4400.00
3400.00
2400.00
1400.00
400.00
-600.00
-1600.00
0
4.26
8.52
12.78
17.04
21.30
25.56
TIME, MS.
YAW ANGLE
YAW VEL.
YAW ACC.

FIGURE 43a



NORMAL ACCELERATIONS
8 INCH PROJECTILE, MK-16 GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ. WALL THICKNESS .40 IN.
CURVE 1---ACC. AT CENTER OF GRAVITY
2---ACC. AT BOURRELET CENTER
3---ACC. AT AXIAL POINT 15.0 IN. FROM NOSE
4--- " " " " 7.5 " " "
5--- " " " " 5.0 " " "
6--- " " " " 2.5 " " "
ACCELERATION, G'S
12.50
10.94
9.38
7.81
6.25
4.69
3.13
1.56
0
4.26
8.52
12.78
17.04
21.30
25.56
TIME, MS.

FIGURE 43b

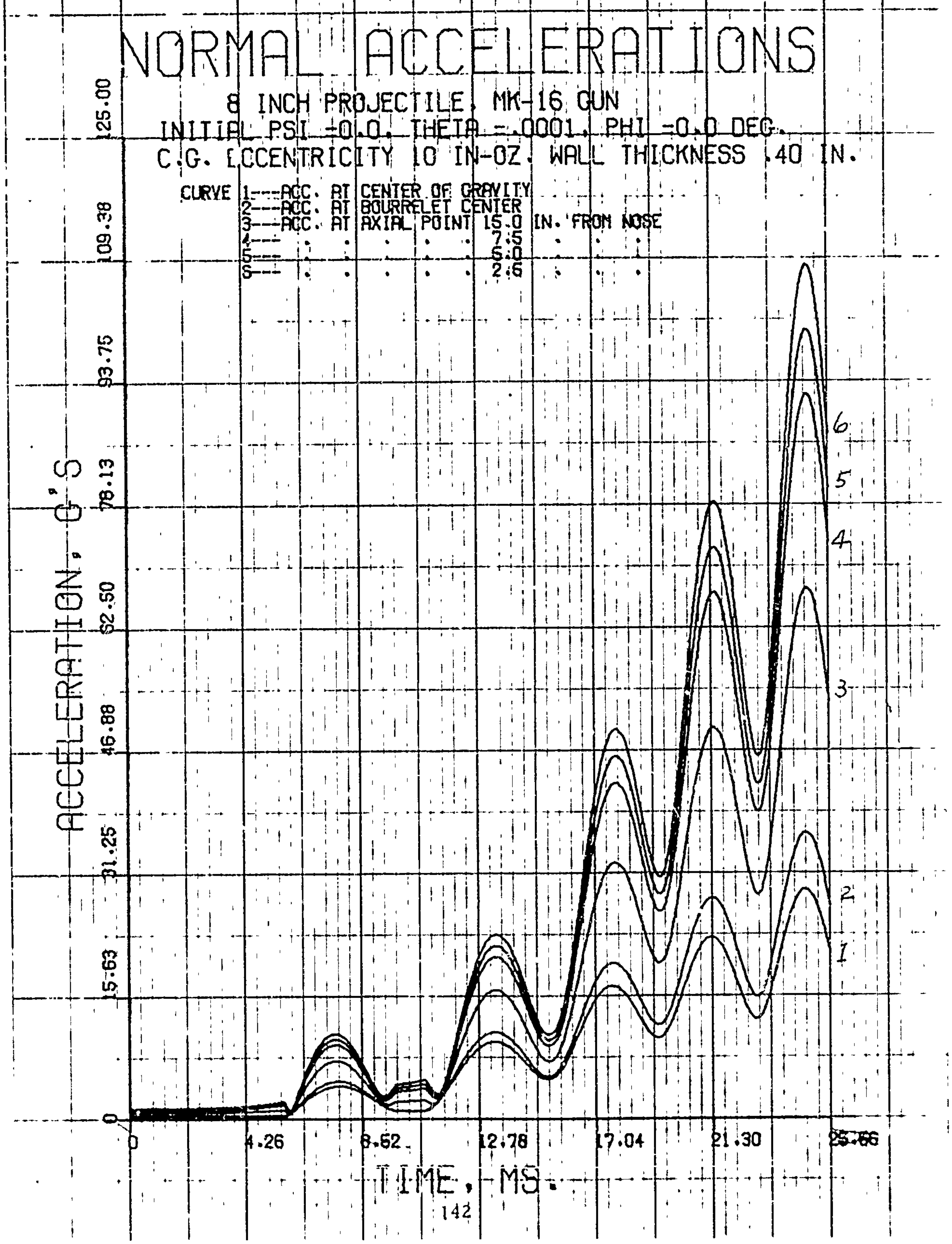

NORMAL ACCELERATIONS
8 INCH PROJECTILE, MK-16 GUN
INITIAL PSI =0.0, THETA = .0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ, WALL THICKNESS .40 IN.
CURVE 1---ACC. AT CENTER OF GRAVITY
2---ACC. AT BOURRELET CENTER
3---ACC. AT AXIAL POINT 15.0 IN. FROM NOSE
4--- . . . . . . 7.5 . . .
5--- . . . . . . 6.0 . . .
6--- . . . . . . 2.6 . . .
ACCELERATION, G'S
125.00
109.38
93.75
78.13
62.50
46.88
31.25
15.63
0
TIME, MS.
0
4.26
8.52
12.78
17.04
21.30
25.56
6
5
4
3
2
1

FIGURE 43c

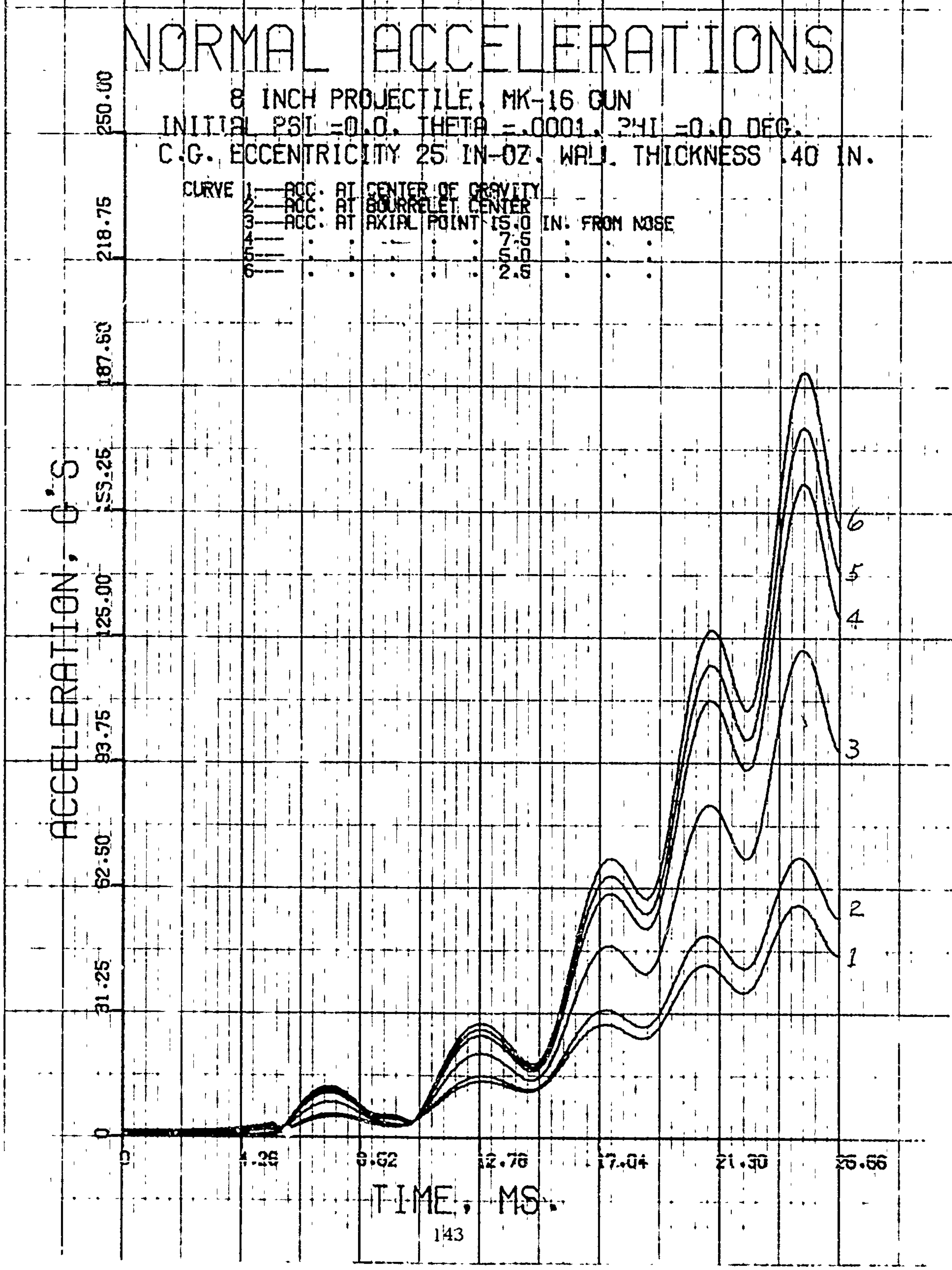
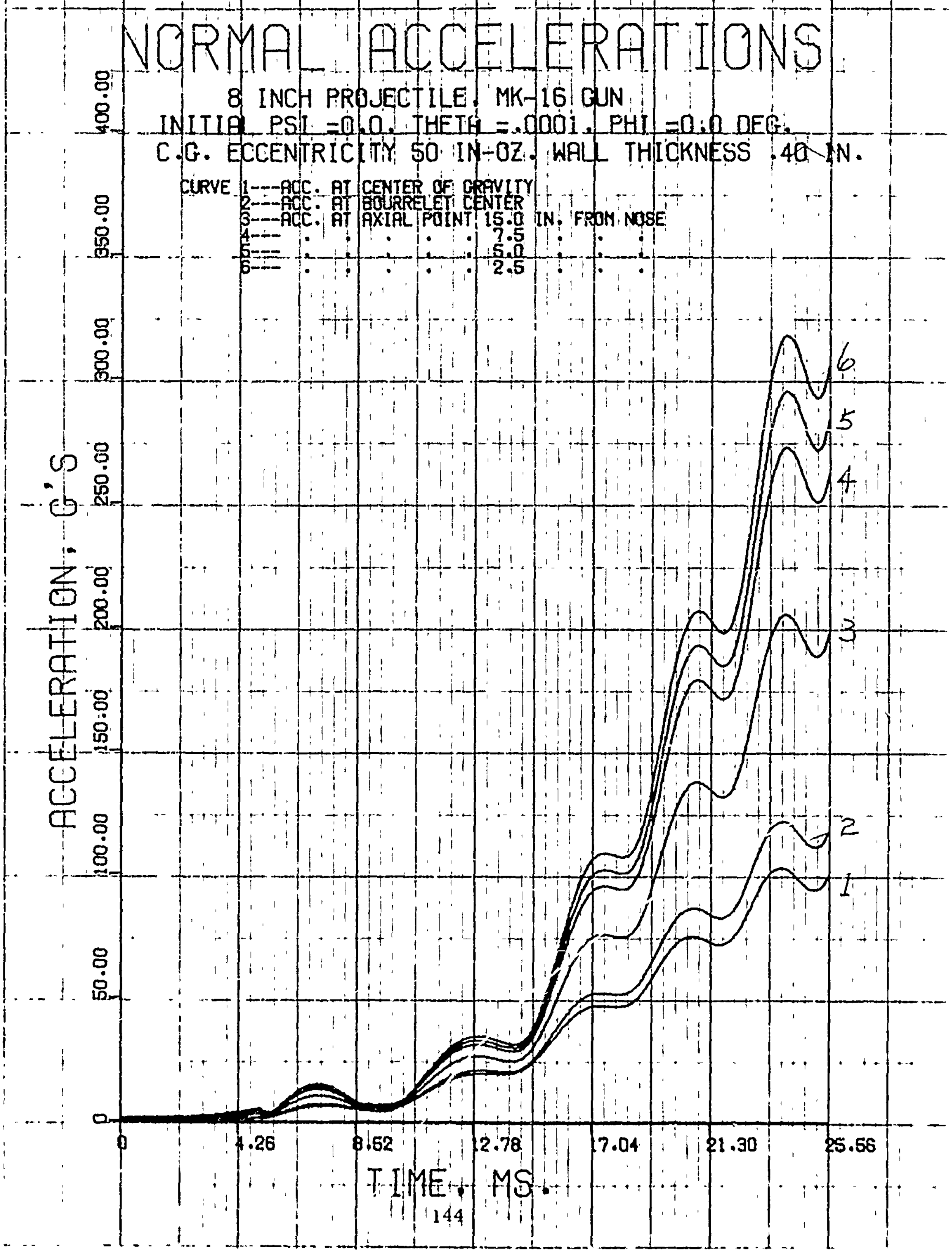

NORMAL ACCELERATIONS
8 INCH PROJECTILE, MK-16 GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .40 IN.
CURVE 1---ACC. AT CENTER OF GRAVITY
2---ACC. AT BOURRELET CENTER
3---ACC. AT AXIAL POINT 15.0 IN. FROM NOSE
4--- " " " " 7.5 " " "
5--- " " " " 5.0 " " "
6--- " " " " 2.5 " " "
ACCELERATION, G'S
250.00
218.75
187.50
156.25
125.00
93.75
62.50
31.25
0
0
4.26
8.52
12.78
17.04
21.30
25.56
TIME, MS.
1
2
3
4
5
6

FIGURE 43d



NORMAL ACCELERATIONS
8 INCH PROJECTILE, MK-16 GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ, WALL THICKNESS .40 IN.
CURVE 1---ACC. AT CENTER OF GRAVITY
2---ACC. AT BOURRELET CENTER
3---ACC. AT AXIAL POINT 15.0 IN. FROM NOSE
4--- . . . . . 7.5 . . .
5--- . . . . . 5.0 . . .
6--- . . . . . 2.5 . . .
ACCELERATION, G'S
0
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
TIME, MS.
0
4.26
8.52
12.78
17.04
21.30
25.56
1
2
3
4
5
6

FIGURE 44a

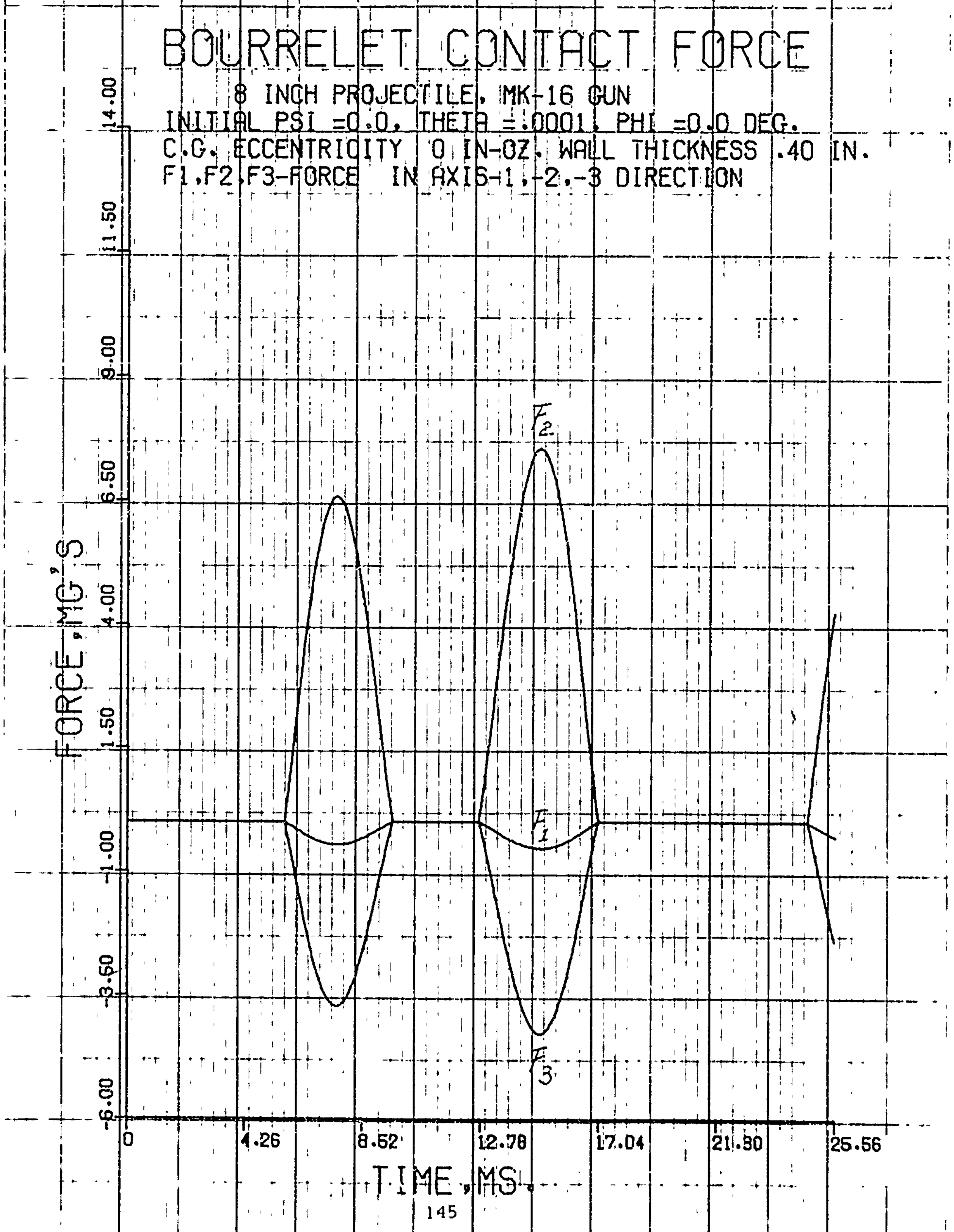
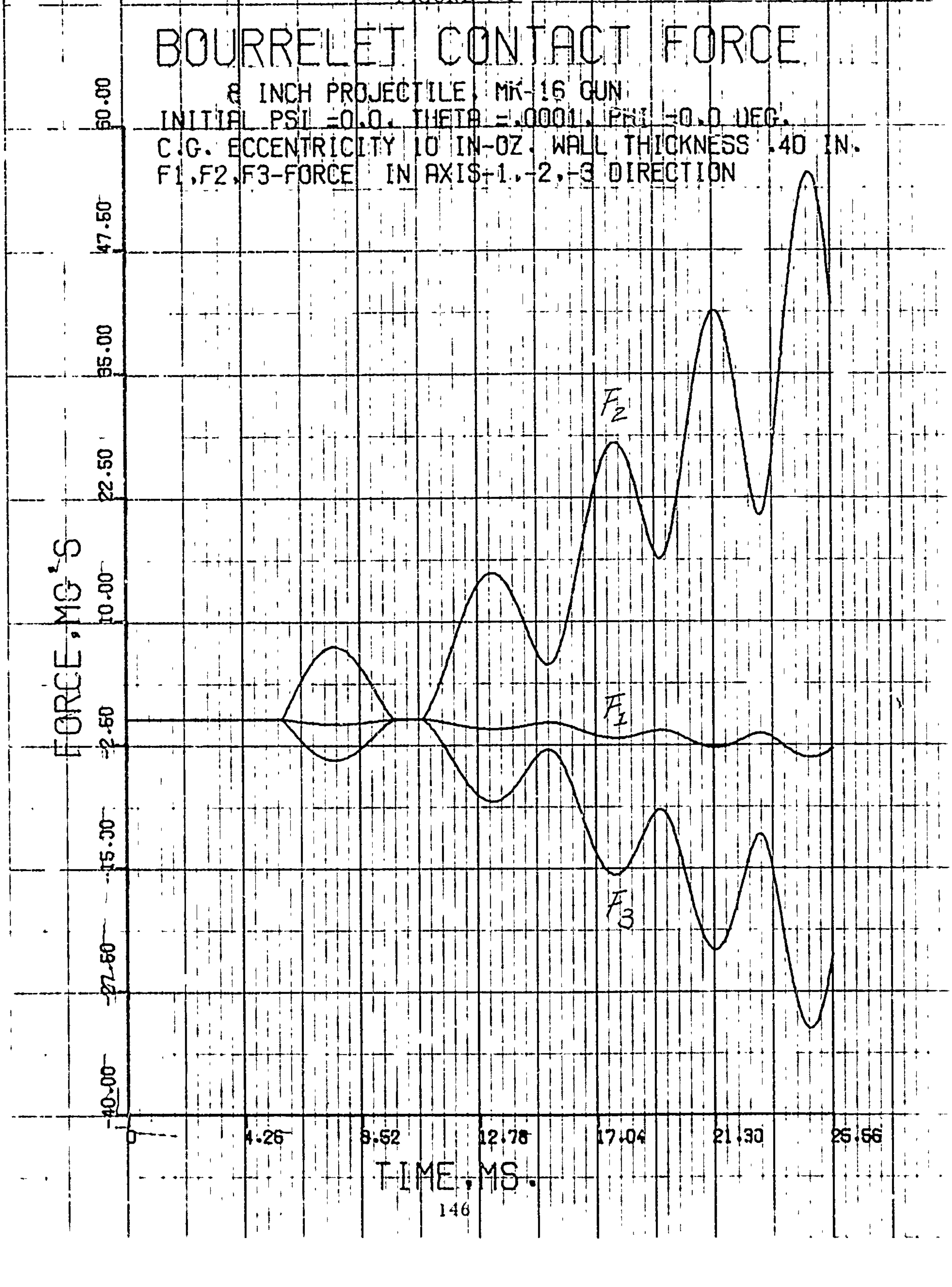

BOURRELET CONTACT FORCE
8 INCH PROJECTILE, MK-16 GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 0 IN-OZ, WALL THICKNESS .40 IN.
F1,F2,F3-FORCE IN AXIS-1,-2,-3 DIRECTION
FORCE, MG'S
14.00
11.50
9.00
6.50
4.00
1.50
-1.00
-3.50
-6.00
TIME, MS.
0
4.26
8.52
12.78
17.04
21.30
25.56
F2
F1
F3

FIGURE 44b


BOURRELET CONTACT FORCE
8 INCH PROJECTILE, MK-16 GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 10 IN-OZ. WALL THICKNESS .40 IN.
F1,F2,F3-FORCE IN AXIS-1,-2,-3 DIRECTION
FORCE, MG'S
TIME, MS.
F2
F1
F3
60.00
47.50
35.00
22.50
10.00
-2.50
-15.00
-27.50
-40.00
0
4.26
8.52
12.78
17.04
21.30
25.56

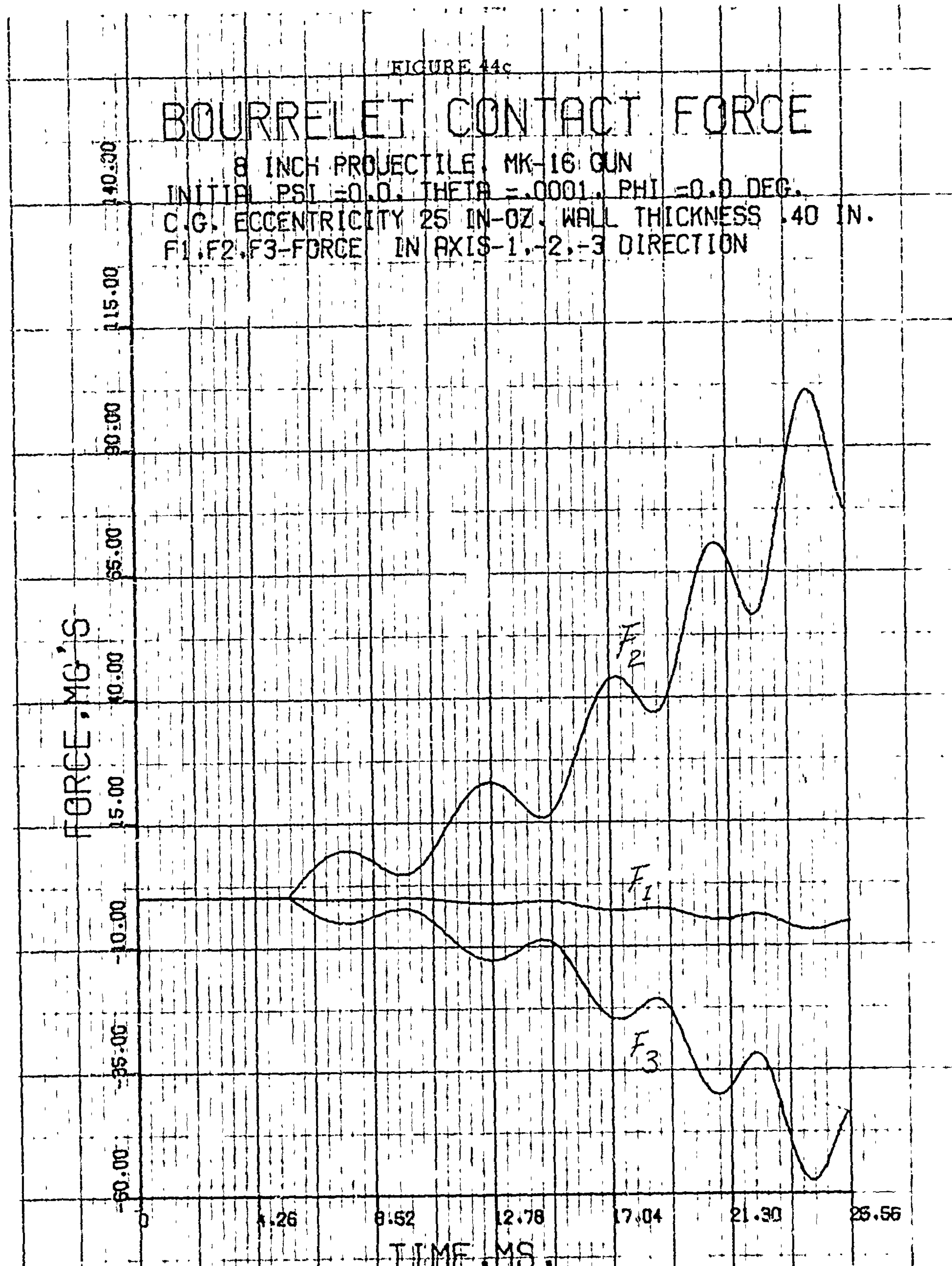
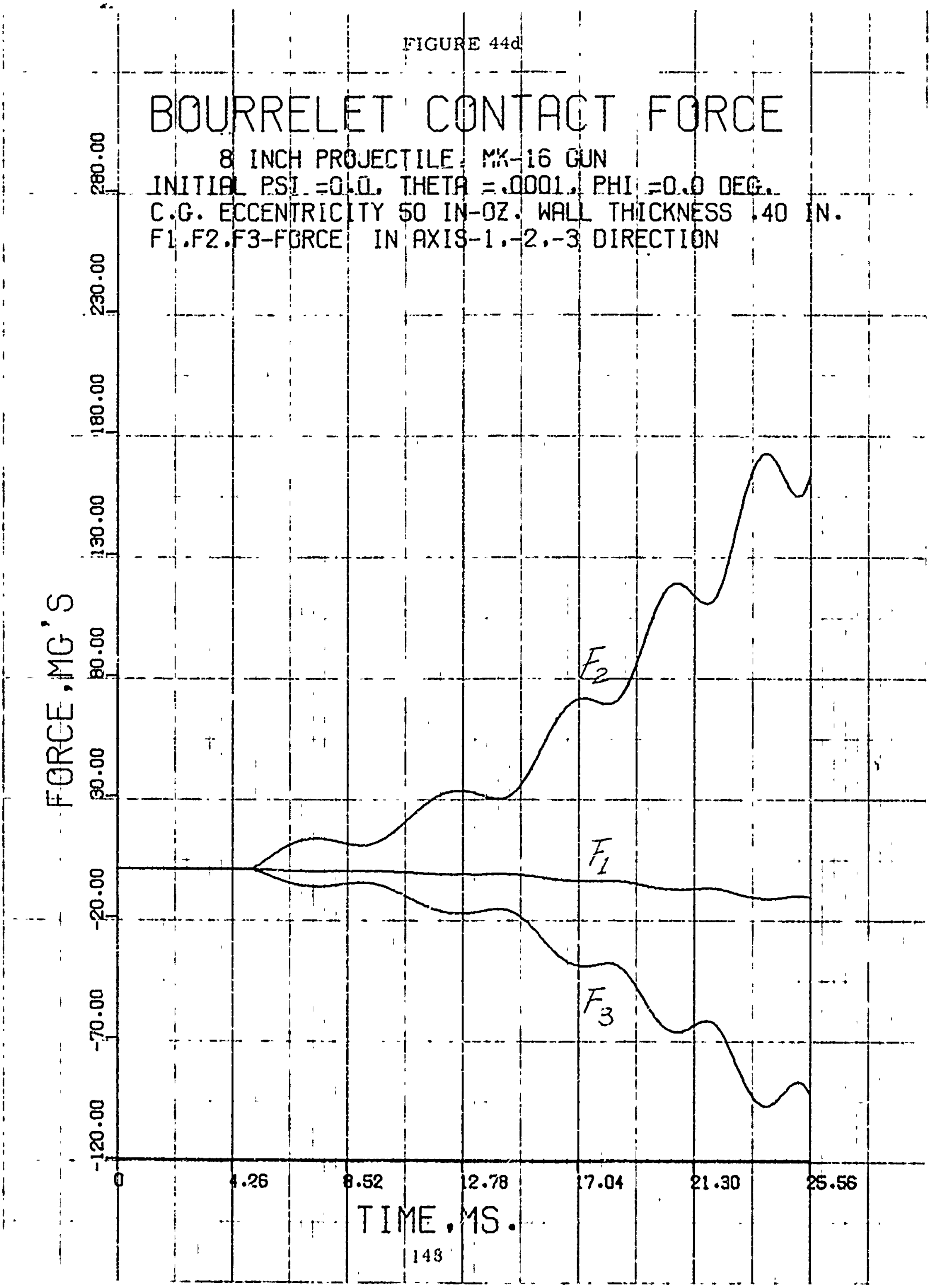


FIGURE 44c
BOURRELET CONTACT FORCE
8 INCH PROJECTILE, MK-16 GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 25 IN-OZ. WALL THICKNESS .40 IN.
F1,F2,F3-FORCE IN AXIS-1,-2,-3 DIRECTION
FORCE, MG'S
140.00
115.00
90.00
65.00
40.00
15.00
-10.00
-35.00
-60.00
TIME, MS.
0
4.26
8.52
12.78
17.04
21.30
25.56
F2
F1
F3

FIGURE 44d


BOURRELET CONTACT FORCE
8 INCH PROJECTILE, MK-16 GUN
INITIAL PSI =0.0, THETA =.0001, PHI =0.0 DEG.
C.G. ECCENTRICITY 50 IN-OZ. WALL THICKNESS .40 IN.
F1,F2,F3-FORCE IN AXIS-1,-2,-3 DIRECTION
FORCE, MG'S
280.00
230.00
180.00
130.00
80.00
30.00
-20.00
-70.00
-120.00
F2
F1
F3
0
4.26
8.52
12.78
17.04
21.30
25.56
TIME, MS.

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13. ABSTRACT

The dynamic behavior of a projectile during acceleration in the gun tube requires a quantitative discription, since if balloting becomes excessive, undesirable conditions such as damage to fuzing, shell body engraving, inaccuracy of fire due to yaw, and yaw velocity at the muzzle may result. The approach taken in this report utilize the equations of motion derived in an earlier report titled, "Transverse Motion of an Accelerating Shell" [1] to descirbe the balloting motion of the 8-inch XM673 projectile fired in the MK-16, MCLG gun, XM201 and M2A2 gun tubes.

Most previous solutions which have appeared in published works to date discuss the problem in a simple way, or consider separately the main factors that effect projectile motion. Effects of friction forces at the bourrelet and the driving band, changes of the eccentricity and the location of the center of gravity, and the wall thickness of the shell were considered in this formulation.

The analysis shows that the contact of the bourrelet on the gun tube is intermittent when the C.G. eccentricity is zero or very small and the contact is continuous when the eccentricity is large and that this parameter is the one that most effects the performance of the projectile and the assoicated fuze. The analytical results are presented in graphic form.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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TRANSVERSE MOTION						
SIDE FORCES						
ARTILLERY						
CANNON						